Mass Customisation for Zero Energy Housing

: the potential of Japanese manufacturing practices in the context of sustainable housebuilding in the United Kingdom

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Thesis Summary

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This research describes the relationship that prefabrication has with sustainable housing. It explains how Japanese housebuilders are using ‘mass customisation’— a phenomenon that mirrors the production and marketing of the automobile sector— to produce zero energy houses and how this applies to the United Kingdom (UK).

The current options for sustainable housing in the UK open market are extremely limited. In contrast, Japanese house manufacturers allow customers to customise their houses in detail, including energy efficiency features. The building energy costs and environmental impact are seamlessly communicated to the customers with brochures and visual information that allow them to make informed choices regarding the design of their houses. With such an approach comes many benefits rarely seen in UK housebuilding, high levels energy-efficiency and personalisation. Japanese house manufacturers are leading the production of zero energy and zero carbon houses.

This research identifies the strategies used by Japanese housebuilders that are suitable for the UK context that would help to increase the production and consumption of sustainable houses

ABSTRACT

This research focuses on describing the relationship that mass customisation has with sustainable housing, particularly with the consumption and production of zero energy houses. It explains how Japanese housebuilders are using mass customisation to produce zero energy houses and how this applies to the United Kingdom (UK).

The current options for sustainable housing in the UK open market are extremely limited. In contrast, Japanese house manufacturers allow customers to customise their houses in detail, including energy efficiency features, through a process known as 'mass customisation'— a phenomenon that mirrors the automobile sector. The building energy costs and carbon impacts, when concerning embodied and operational energy, are seamlessly communicated with sophisticated tools, visuals, catalogues, guides and models that allow customers to make an informed choice. With such an approach comes many benefits rarely seen in UK housebuilding, high levels of quality control through off-site manufacture and critically an opportunity to choose a level of specification. Japanese house manufacturers are leading the production of zero energy and zero carbon houses.

This research consists of a comparative analysis of the Japanese and UK housebuilding, to identify how mass customisation strategies are used to drive the sales of zero energy houses in Japan, and infer how to apply them in the UK.

This research found that some housebuilders in the UK are currently using production strategies that resemble Japanese practices. However, the sustainable benefits observed in the Japanese context are not present in the UK because housebuilders' co-design tools

and marketing strategies are limited and unsophisticated. Production and consumption of sustainable houses would increase in the UK if housebuilders implement full mass customisation, meaning selecting existing robust production processes, defining an appropriate space solution and using informative navigation tools.

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Introduction

This introductory chapter describes the thesis research structure, objectives and research questions. It starts by presenting an overview of the current housing situation in the UK as a theoretical rationale for developing the research. It follows by presenting the research questions, the expected contribution to knowledge and research scope. It also describes the research aims, objectives and expected target readers. This chapter finishes by presenting a brief of each of the section and chapters that compose this thesis.

Background

Houses for sale in the UK are marketed by room count and location. If a buyer wishes to acquire a zero energy/carbon dwelling (or any other type of sustainable dwelling), then the choice available from the open market is extremely limited (Davis, 1987:158, Barlow, 1999:32; Naim & Barlow, 2003:593; Lovell et al., 2010:458). The scarcity of zero energy/carbon housing is not a matter of lack of ability or capacity to produce them, as there are many good examples of such houses in the UK (Zero Carbon Hub, 2009:40–41; Hootman, 2013:2; Guzowski, 2010). However, these are the result of isolated ventures of people with dedication and money to employ an architect (or constructor) for what is essentially a bespoke service. Procuring a dwelling in this way is not only more expensive and time-consuming but unpredictable regarding cost and, ironically, about its energy performance. The benefits of standardisation regarding quality as defined as consistency, price certainty and production efficiencies are lost, causing most house-buyers to opt for mass housing options (Shafik & Martin, 2006:82; Pitts, 2017:9,15). The self-built sector in the UK accounts for 10%, which is five times lower than the average in Europe and seven times lower than in Japan.

In Japan, there is a segment of the housing market where houses are produced on-demand, allowing customers to choose and customise their houses in detail, even in terms of energy efficiency (Davies, 2005:186–192; Yashiro, 2014:20; Aitchison, 2018:94-96). These housebuilders involve the customer in the design decision-making process through a sophisticated process known as ‘mass customisation’— a phenomenon that mirrors similar developments such as in the automobile sector (Davis, 1987:158; Barlow et al., 2003:137–139; Barlow, 1999:30; Gann, 1996:447).

With such an approach comes many of the benefits rarely seen in UK housebuilding, high levels of quality control through off-site manufacture and critically an opportunity to choose a level of specification regarding energy efficiency. Although the customer is empowered, in reality, it is predicated on a circumscribed number of variants of pre-designed houses. The building energy costs and carbon impacts, regarding embodied and operational energy, are seamlessly communicated with sophisticated tools and visuals that allow consumers to make informed choices (Davies, 2005:188). In contrast to the UK situation where house-buyers very often must commit, almost as an article-of-faith, to a zero-carbon solution from the very beginning of the procurement process (Hootman, 2013:27).

In the UK, there is a general appreciation for practices that promote sustainable consumption and energy efficiency (HBF, 2019:1). The government has committed to the reduction of carbon emissions[1] and has continuously pushed the housing sector to improve their practices to achieve lower carbon solutions (Farmer, 2016:20,62; MACE, 2018:6,14; Zero Carbon Hub, 2013:1; Pan et al., 2007:12). However, the market of zero energy/carbon and energy-efficient houses remains limited.

[1] The UK committed to reducing carbon emissions within the signing of the Kyoto Protocol (Fankhauser et al., 2008:99; Ares, 2016:3).

Research questions

Mass customisation is a production system highly practiced in the Japanese housebuilding sector, which is not the case in the UK (Barlow & Ozaki, 2001:1-5; Barlow, 1999:23-26; Bardakci & Whitelock, 2003:471; Davis, 1987:158; Knaack et al., 2012:54-55; Piroozfar & Piller, 2013:7). The Japanese housebuilding sector that uses mass customisation is recognised for leading the production of zero energy houses (Noguchi et al., 2016b:339; Noguchi, 2013b:166-167; Noguchi & Hadjri, 2010:898,903; Iwashita, 2001:295). The high production of zero energy houses in Japan could be related to the use of mass customisation in housing production, marketing, and selling processes; therefore, this thesis set the following research question.

- ***What relationships can there be between Mass Customisation and the production and performance of Zero Energy houses?***

Understanding how mass customisation relates to the production of zero energy houses in the Japanese context, could provide a theoretical explanation of the relationship between mass customisation and sustainability. However, the Japanese and UK contexts are very different (Johnson, 2007:27-41; Ballas et al., 2014:103-104; Tiwari et al., 2018; Barlow et al., 2003:134-135). The Japanese housing practice is specific to the Japanese context; and therefore, the implementation of their housing practice might not be appropriate for the UK context. Consequently, this thesis also set the following research questions.

- ***What aspects of the Mass Customisation model of the Japanese housing context could be implemented in the UK?***

- ***How to implement Mass Customisation in the UK context to increase the production/consumption of zero energy houses in the UK context?***

These research questions require an understanding and contextualisation of mass customisation techniques. Primary research was employed both in a Japanese and UK context to address these research questions specifically in terms of replicability and suitability in different construction and property markets.

Aims and objectives

This research aims to critically examine the production of houses in the UK and Japan to suggest the implementation of mass customisation strategies observed in Japan as an effective strategy to produce zero energy houses in the UK. Thus, this research aims to understand the mass customisation production of houses in Japan to identify which aspects are exclusive to the Japanese context. In parallel, understand the off-site production of houses in the UK to identify the aspects that resemble mass customisation or that are suitable for the implementation of mass customisation. Finally, describe how UK housebuilders could implement mass customisation strategies. The following diagram conceptualuse the aim of the research. It exemplifies that the objective of the research was to find the matching point between the housing practices of Japan and the UK that were not exclusive to their contexts. The arrows represent the selected housing practices of each context. Off-site manufacturers in the UK and mass customisers in Japan, business models that are explained in Chapters 5, 6 and 7. The dashed line represents the analysis criteria to set the exlusive aspects of each context, particularly explained in Chapter 4. The ‘Body of Knowledge’ refers to the findings of the research defined in Chapter 6, 7 and 8 (Fig. 1).

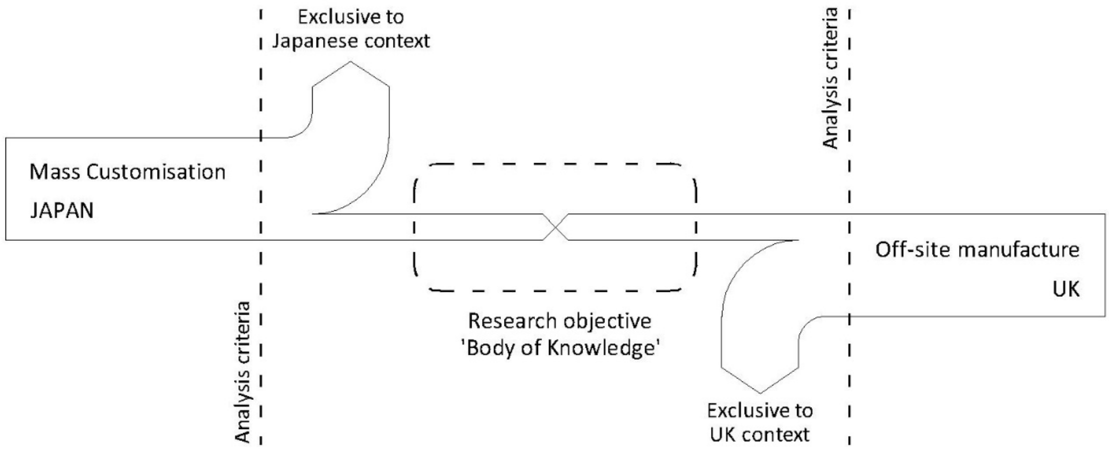

Figure 1. Diagram of the research objectives.

The objectives of this research are:

1. *Understand the conceptual relationships that mass customisation has to sustainability overall*— This will be primarily undertaken through literature review.

2. *Identify how mass customisation assists Japanese volume housing providers to deliver high levels of energy efficiency in their dwellings*— This is undertaken through literature review and fieldwork to understand the use of mass customisation in the design, production and marketing of dwellings.

3. *Understand key housing supply and demand drivers in Japan and the UK and ascertain the reasons for the adoption of context-specific procurement processes*—This is undertaken through literature review, review of industry data and embedded governmental and industry policies.

4. *Identify what mass customisation strategies employed by Japanese house manufacturers may be applicable in the UK*— This is undertaken through a combination of fieldwork, literature review and critical analysis of industry data.

Additionally, this thesis aims to join a growing area of interdisciplinary research on housing and sustainability. It does not attempt to theorise concepts of sustainability, nor argue the fundamental case for sustainable practices; instead, it explores the applicability of sustainable strategies in the housing practice.

This research is intended as a reliable source for referencing to mass customisation and zero energy buildings and as an archive of economic and production data of the selected housebuilders from 2015-2019. It also intends to act as a guide for those interested in mass customisation processes in relations to housing practice and the opportunities and barriers of adopting a manufacturing approach to house construction.

Contribution to knowledge

This research describes one of the multiple connections that industrial production has with housing and sustainability, which is a concurrent argument in the discourse of modern architecture (Gropius, 1956:143-150; Habraken, 1972:50-52; Le Corbusier, 1974:100-139; Banham, 1984:122-123; Davies, 2005:7-10; Williams, 2012:224-226; Kieran & Timberlake, 2004:15-24,155-173).

Industrial production has been presented as a potential solution for reducing energy consumption and carbon emissions of the housing sector (Farmer, 2016:20,62; Reynolds & Tate, 2018:14; Noguchi, 2013b:164; Pan & Goodier, 2012:17-24; Heffernan et al., 2015:23-24). This research contributes to knowledge by presenting mass customisation as a solution to produce sustainable houses using the advantages of existing industrial manufacturing.

Scope

This research introduces mass customisation strategies related to energy efficiency used in the Japanese 'on-demand' housing context that are applicable to the UK.

Consequently, it deals with: theoretical definitions of mass customisation and zero energy, including mass production, customisation (craft production), solution space, mass customisation enablers and (net) zero energy/carbon building; theories of mass production and mass customisation from a general perspective to the specifics related to house production; socioeconomic data of Japan and the UK with particular emphasis on the housing sector; the role of 'the land' in the housing business; customer-oriented marketing; and data related with the economies and production capacities of selected housebuilders and manufacturers of Japan and the UK.

This research focused only on the production and consumption of new single dwellings sold on the open market. The thesis does not advocate any particular planning or urban design strategy for settlements and instead is concerned with the production of new homes, not the context in which they are placed. The research also does not explore mass housing and housing for rent because they have characteristics that do not sit well with the principles of mass customisation (Habraken, 1972).

Thesis structure

This thesis was structured in the following eight chapters.

Chapter 1: ***Introduction*—** This chapter (referring to the present chapter) explains the reasons and background rationale for conducting the research. It presents the aims of the research, research questions, objectives and describes its structure.

Chapter 2: ***Research Methodology***— This chapter describes the methodology applied in carrying out this research. It explains 'why' the methodology was selected, 'what' is it and 'how' the research was developed. This chapter links the rationale of the study with the methodology section. It describes the philosophy underpinning the research, the research approach, strategies, design, time horizon, methods used for data collection, unit of analysis and data analysis techniques.

Chapter 3: ***From ZEMCH to Mass Customisation for Zero Energy Houses***— This chapter focuses on defining the acronym ZEMCH, which currently stands for Zero Energy Mass Custom Home. This chapter focused on defining ZEMCH as a single concept rather than as a contraction of different terms. It presents existing research on the topic and explains relationships between the goal of 'zero energy' and processes of 'mass customisation'. The chapter's objective is to define the terms in such a way as to demonstrate strong links between two phenomena that are often part of different research domains. The argument of this chapter was composed using texts produced by the ZEMCH Network, an interview with Masa Noguchi, related literature review; and exemplified through a series of examples in practice.

Chapter 4: ***Contextual comparison: Japan is Japan, and the UK is the UK***— This chapter presents a comparison between Japan and the UK housing contexts. This chapter consists of a literature review that narrates the historical description of the housing strategies used in Japan and the UK from the end of the Second World War until current conditions; the different conditions of each context and how these affect the land distribution, availability and housing models; the differences in their planning systems; the different housing needs of each context; and the different legislation related to energy consumption in households and how this affects the housing practice.

Chapter 5: ***Macro description of Housing models and why the transfer of Japanese manufacturing technology is not on***— This chapter consists of a literature review that compares the UK speculative housing sector and Japanese mass customisers housing models, and explains why the implementing of industrial machinery aspects present in the Japanese housebuilding are not appropriate for the UK context. It describes the housing processes from a customer perspective. This chapter explains the risks of investing in manufacturing technology and machinery in the housing industry through examples. It also describes the importance of lean and agile manufacturing systems and how these are not strictly attached to investments in industrial machinery and the importance of market-orientation in mass customisation.

Chapter 6: ***The Back Office: manufacturing capacity and processes*****—** This chapter consists of a description of the production processes of selected Japanese house manufacturers and UK house manufacturers through information, data and material collected in the fieldwork. It analyses the selected companies; two Japanese house manufacturers and three UK manufacturers involved in housebuilding. This chapter describes how the UK manufacturing industry possesses a robust capacity suitable for the implementation of mass customisation.

Chapter 6: ***Front House: the power of informed customers*****—** This chapter consists of a description of the marketing, co-design and selling strategies of selected Japanese house manufacturers and UK house manufacturers through information, data and material collected in the fieldwork. It analyses the selected companies; three Japanese house manufacturers and two UK manufacturers involved in housebuilding. This chapter describes the Japanese housing mass customisers' marketing, co-design and selling strategies, to explain the relationship between these and energy efficiency. This chapter also describes which strategies used by the selected Japanese companies are suitable for the UK context and under which conditions.

Chapter 8: ***Conclusions*****—** This chapter summarises the content of the thesis drawing out key aspects of the information collected along with conclusive findings. This chapter includes a reflection on how the initial hypothesis relates to the conclusions, showing where it contradicts and where it is justified. This chapter concretively answers to the research questions established in chapter 1 and describes how the research hypothesis relates to the findings of this research. It also mentions the research limitations, opportunities and potential further research.

Appendices— This section is an addition to the body of the thesis and contains material elaborated during the research process. It includes the transcriptions of the interviews developed for this research. An academic paper concerning the barriers to building a zero energy prototype in Scotland, named 'Barriers to Innovative Housing in Scotland: NRGStyle's 'ZEMCH 109' Case Study'. An essay on the topic of Home, named 'H is for Home', developed in coordination with Hafsa Olcay. A short story as an analogy for explaining the co-design process of house manufacturers in Japan, named 'The House that designed his house'. It also includes graphical representations and visual aids created as part of the research process, like a timeline and visual maps used to relate the information collected.

Chapter 2

Research Methodology

This chapter describes the methodology applied in carrying out this research. It explains 'why' the methodology was selected, 'what' is it and 'how' the research was developed. This chapter links the rationale of the study with the methodology section. It continues by describing the philosophy underpinning the research, the research approach, strategies, design, time horizon, methods used for data collection, unit of analysis and data analysis techniques. This description will also elaborate on how this research interprets each of the concepts and explains the reasons for the selection of each method or strategy. This research has selected 'triangulation method' as a research methodology. 'Literature review', 'Fieldwork' and 'Grounded Theory' are the research methods used in the development of the research. This chapter concludes by summarising the analysis/information presented in the form of a table to allow the reader to visualise the interrelationships between the design methods and strategies.

Introduction

This research puts forward the hypothesis that Japanese manufacturers are leading the production of zero energy houses because of the use of mass customisation; and that therefore, the implementation of mass customisation in the UK could increase the production of zero energy houses.

This hypothesis combines theoretical and empirical suppositions. It suggests theoretical relationships between mass customisation and sustainability, and enquire about the practicalities of adopting Japanese business and manufacturing techniques.

The topics in concern— mass customisation, energy-efficiency and housing— are categorised in different academic disciplines; mass customisation relates to business, energy-efficiency to engineering and sustainability, while housing to architecture and urbanism. The study of varied disciplines tends to favour the use of different methodologies (Wisker, 2008:114). There is an increasing tendency in research to use 'mixed methods', not only for its effectiveness and practicality, but as a process of increasing the scope of the research and avoid bias (Walsh, 2015:531; Moran-Ellis et al., 2006:54; Strauss & Corbin, 1998:13; Vaivio & Sirén, 2010:132; Rothbauer, 2008:892; Feilzer, 2010:6-10,13-14).

The methods used in this research were selected to correspond to the material collected for this study. Importance was given to the selection of adequate data collection methods that help to meet the objectives of the research (Opoku et al., 2016:32).

This research covered two different contexts—Japan and the UK. The contextual differences did not allow the use of the same research techniques in both countries. Differences in language and measurement units (currency, financial and economic indicators) required the use of different techniques to extract and manage the data collected from the fieldwork. The data collected in this research varied in form, source, type and even language. For example, the information provided by the manufacturers visited in the fieldwork could be provided as brochures, technical tours, personal meetings or PowerPoint presentations; all of which needed to be homogenised to comparable data. Therefore, the use of mixed methods was required, as different types of data required different collection methods and analysis processes. Accordingly, ‘triangulation’— a method used to achieve a single conclusion from different perspectives— was selected as the research methodology (Drisko, 2011).

Research Methodology— *‘triangulation’*

This research understands ‘research methodology’ as the planning, process and combination of research methods and techniques needed to reach a research conclusion (Rajasekar et al., 2013:5; Walsh et al. 2015:584; Opoku et al., 2016:32).

Triangulation is a research method constructed as an analogy of the triangulation measurement techniques used by navigators and surveyors[2]. These techniques are mathematical approaches used to locate objects, or *unknown fixed points* in space by relying on known points in that same space (Rothbauer, 2008:892). Social scientists borrowed the concept of triangulation for its use in the validation process of assessing research results (Mertens & Hesse-Biber, 2012:75); as eloquently expressed by Isabelle Walsh (2015:551)– researcher focused on the use of systemic action research– as,

> *‘...mixed data help mathematicians to bring context into their abstract world and sociologists to accept help from mathematicians to decipher existing patterns in their data.’*

In terms of research methodology, triangulation is more precisely referred to,

> *‘… a technique used to accurately increase fidelity of interpretation of data by using multiple methods of data collection.’ (Kolb, 2012:85)*

2 Referring to ‘Surveyor’ as the person who examines the condition of land and buildings professionally.

Triangulation was selected because it is an effective method to cross-check the findings of each of the collection methods (Vaivio & Sirén, 2010:132; Rothbauer, 2008:892). The nature of this research, regarding its multidisciplinary approach and clarity of material collected, determined the use of multiple research methods. This study focused on housing– a complex system that involves, not only the construction of houses, but also the relationships between housebuilding, stakeholders, future-users, economics, geography, architecture and urban planning– which required to have a perspective where the whole system could be understood and analysed; because at the point of starting the research, it was not clear which aspect of the system was the one where the research needed to focus, or if it needed to relate to the whole housing system (Habraken, 1972). Thus it was essential to specify the research stance, philosophy of research and research paradigm.

The philosophy of the research– *Research paradigm*

This research understands 'research paradigm' as a synonym of 'disciplinary matrix', defined as the conventional system of beliefs shared by members of a particular scientific community, namely, the set of techniques, models, and values to which the group members more or less consciously adhere (Agamben, 2009:11; Kuhn, 1970:182; Walsh et al. 2015:584).

Studies in energy efficiency tend to follow a generally accepted disciplinary matrix based on experimental research methods that concentrate on testing the technicalities of construction or performance of buildings. Simulation modelling, as an example, is an efficient, and valid, research approach for testing hypotheses, making predictions and improvements to the performance of buildings and mechanical systems. However, simulation studies often falter when it comes to their implementation in housing practices (Gilbert & Troitzsch, 2005:15; Dooley, 2002:23,31).

This research preferred to follow a 'pragmatic approach' and 'systemic stance' as research paradigms. A pragmatic approach refers to the analysis and solving of a problem as a human activity, in which housing– as a human activity– is considered the research framework (Morgan, 2014:1046). In this sense, pragmatism allowed to free this research of constraints imposed by research traditions, meaning that the research does not have to restrict itself to one method or technique; allowing a more systemic approach that matches with the disciplines of this research (Feilzer, 2010:8).

Systemic research or 'systems thinking', is a response to intractable problems that have proved to be resistant to simple solutions, as the hard task of producing sustainable (energy efficient) housing (Burns, 2014:4). This is because the problem of sustainable housing is characterised by vicious cycles, multi-directional causality and non-linear change where the interaction of multiple factors produces undesirable outcomes– houses that do not fill the energy requirements of users and governmental sustainability goals (Parvin et al., 2011; Piroozfar & Piller, 2013:4).

Systems thinking is characterised by a focus on the relationships and interconnections rather than actors and institutions. Housing systems are dynamic, they respond to the changing social needs, technological improvements in construction, economies, environmental changes, among multiple factors, including the inclusion of relevant stakeholders (Habraken, 1972). When something in a system changes, it changes the relationship between the other parts of the system; as the unintended increasing desire for sustainable housing. In which, is possible to create change in one part of a system even though the ‘problem’ appears to be in another part; thus, the solution cannot be attributed to an individual intervention and requires a systemic understanding of how changes happen (Hammond, 2017:16; Burns, 2014:4-5).

Early in this research, it was realised that the issues for the production of zero-energy houses were not related to technical or technological aspects of the housing system (Hootman, 2013:2; Guzowski, 2010). Eventually, this research settled on that aspects that could help to increase the production of zero-energy houses related to marketing and communication, which were probably not visualised if the research was not conducted from a systemic thinking perspective.

Sustainable processes are associated with holistic perspectives, which runs coherently with the definition of sustainable development. This research aims to provoke sustainable changes in the housing system by promoting the production of zero energy houses, in which analysing the system was beneficial to generate sustainable transformations in the housing systems. Danny Burns (2014:7)– researcher focused on the use of systemic research– explains the aspects of systemic thinking that relate to sustainable development as follows:

> *‘...change is always possible, but sustainable change requires us to change the system within which the changes are taking place. This denotes a shift in focus from problem solving to system reconfiguration and means that change requires engagement across the system.’*

Therefore, this research followed a pragmatic systemic thinking stance to achieve the research goals and answer to the research questions in the most accurate manner. It rejects the use of research paradigms that focus on experimentations because of their limited implementation in housing. This research uses multiple approaches to eliminate any potential biases and follows a well-structured pragmatic analysis based on an original theoretical framework. Therefore, it used a mixed methods approach to produce results that have a direct impact in practice (McDonald, 1985:22,39; Smith & Noble, 2014:100).

Research approach– *Mixed methods*

This research used a mixed methods approach, which refers to the research approach that involves using quantitative and qualitative research methods, integrating multiple forms of data (Creswell, 2014:4; Migiro & Magangi, 2011:3757; O'Cathain et al., 2010:1).

This research required to set a pragmatic approach rather than a philosophical assumption, which is a broadly accepted practice in the field of mixed methods research (Biesta,2015; Brannen, 2005:8; Bronstein & Kovacs, 2013:355; Morgan, 2014:1045). Mixed methods and techniques have received increased attention and have been used for obtaining a holistic perspective of studied phenomena (Walsh, 2015:534). Therefore, using mixed methods was considered as the most appropriate research approach. Thus, a pragmatic mixed method approach was adequate to cope with the variety of contexts and types of data involved in this research (Feilzer, 2010:6-10,13-14).

The mixing of quantitative and qualitative research methods was divided into different phases. In initial stages, they were running separately and in final stages, after the analysis of the data, they were mixed to produce the written argument presented in this thesis, as described in the following diagram (Table 1).

Table 1. Mixed method phases

<table>
<tr><td colspan="5">Research material</td></tr>
<tr><td>Parallel processes</td><td colspan="2">Qualitative
Research Methods</td><td colspan="2">Quantitative
Research Methods</td></tr>
<tr><td>Type of material</td><td>Interviews</td><td>Interpretation of Brochures</td><td>Numeric data
from primary sources
(production volume,
machinery used, etc)</td><td>Numeric data
from secondary sources
(production volume,
financial data, etc)</td></tr>
<tr><td rowspan="2">Phase 1</td><td>Transcritpt & coding</td><td>Coding</td><td colspan="2">Generation of data matrices</td></tr>
<tr><td colspan="4">Analysis of data</td></tr>
<tr><td rowspan="3">Phase 2</td><td colspan="4">Mixing of methods</td></tr>
<tr><td>Quoting from interviews</td><td colspan="2">Diagrams</td><td>Final tables</td></tr>
<tr><td colspan="4">Writing of thesis</td></tr>
</table>

This table is a conceptual description of how the qualitative and quantitative data was gathered and analysed, using parallel processes in the early stages of the research and then merged for the development of the research argument. The data collection and analysis techniques are described in more detail in the ‘Collection and analysis of data’ section.

Research methods

This research used three methods, or research strategies, as part of the whole research methodology: ‘literature review’, ‘fieldwork’ and ‘grounded theory’. The literature review was used to contextualise the study with current knowledge and provide a reference for the interpretation of the findings. It was used to complement quantitative data by extracting information from scientific journals, specialised books and other secondary sources; and support theories built from qualitative data. Fieldwork was the medium used to collect primary source materials. It was the main source of data, both quantitative and qualitative data. Grounded theory was the method used to analyse data obtained from the literature review and fieldwork and elaborate on the research argument.

This research selected these strategies because these are compatible with systemic thinking, pragmatism and triangulation; but more important because they follow the type of data collected (Biesta, 2015; Denscombe, 2007:92; Strauss & Corbin, 1998:8; Walsh et al., 2015: 582,586,587; Kolb, 2012:84; Eaves, 2001:655). This thesis utilised literature review, fieldwork and grounded theory as follows.

Literature review

This research understands 'literature review' as an objective, thorough summary and critical analysis of the relevant available research and non-research literature on the topic studied (Cronin et al., 2008:38; Hart, 1998:1-25).

First, literature was used to elaborate on the theoretical framework and the rationale of the study (Walsh et al. 2015:584; Lederman & Lederman, 2015:594). As an example, in chapter 2 (the chapter in question), literature was used to justify the selection of the research methodology and strategies.

Then, this research used literature review to determine if the topic in question had original value; to identify, evaluate and interpret the work of others to establish the status of the current study; and cross-validate findings providing references for their interpretation

(Rocco & Plakhotnik, 2009:122,125; Creswell, 2014). This action was repeated in different stages of the research whenever a new topic needed to be developed. Examples of it are Chapters 4 and 5, in which topics not directly connected to zero energy and mass customisation were developed to understand the factors of the housing system that affects them. In Chapter 4, the contexts of Japan and the UK were described focused on the 'use of land' and its transformations into housing and other socio-economic factors that make each context particular. It was developed entirely as a literature review. Chapter 5 describes the housing procurement systems of selected housing typologies in each context. It was also developed entirely as a literature review. The topics of these couple of chapters were selected as a consequence of the research progress. Chapter 4 is linked to the findings of the initial literature review (which most of its content was integrated to Chapter 3, explained further below); and Chapter 5 was linked to the analysis of data collected from the fieldwork, which was used to elaborate Chapter 6 and 7. Also, the selection of the methodology and research methods was selected following a review of literature, which ran into the research process and through the whole process. Chapter 2 was developed also entirely as a literature review.

The literature review was used to introduce the chapters produced through other methods, as Chapters 3, 6 and 7. Chapter 1 is the introduction of the whole thesis and was also developed supported with information gathered from literature.

Finally, the literature review was used to support the theory built through grounded theory. Chapter 3 is dedicated to the generation of new theory– the definition of ZEMCH and of the relationships of zero energy and mass customisation. Literature review is widely used through Chapter 3 in relationship with qualitative data extracted from the fieldwork. Accordingly, the literature reviewed was rooted in texts developed by the ZEMCH Network and Masa Noguchi.

Fieldwork

This research used fieldwork as a strategy to collect primary source material and observe the context first-hand (Strauss & Corbin, 1998: 9). The fieldwork consisted of collecting quantitative and qualitative data using observational methods, surveys and interviews (Burgess, 2000:2). The fieldwork relied on the commitment of the researcher to the object of study— in this case, the housing manufacturing context (Pole & Hillyard, 2016:3).

The fieldwork consisted of visiting the facilities of housebuilders and manufacturers involved in housebuilding in Japan and the UK, and in interviewing people that practice or which research expertise have focused on processes related to mass customisation or zero energy housing.

- *Japan*— The fieldwork in Japan consisted of visiting and recording the facilities, selling points and building prototypes of companies involved in the manufacturing and marketing of mass customisable houses. It included visits to manufacturing facilities, show houses, housing prototypes and areas used for displaying technological components and exhibitions (information centres). The fieldwork in Japan included the development of an interview with Masa Noguchi concerning aspects of the conception of the ZEMCH term that supported the construction of Chapter 3.

- *The UK*— The fieldwork in the UK involved visiting and recording the facilities of companies engaged in the manufacturing of houses and housing components. It included visits to research centres, housing prototypes and a construction fair. The fieldwork in the UK included the development of multiple interviews. Mike Cruickshank was interviewed in the visit to the Scotframe facilities and focused on aspects related to the design and production of houses. Interview with Ben Murphy external to the visit to Robertson's facilities. These were used for the construction of Chapters 6 and 7. Qualitative and quantitative data was extracted from these interviews. The characteristics of the interviewees are explained further in the 'Interviews' section of this chapter.

Five interviews were conducted in this research as part of the fieldwork. The interviewees' profile, type of interview and their importance in the research argument are described as follows.

Masa Noguchi— Associate Professor in Environmental Design at the Faculty of Architecture, Building and Planning, University of Melbourne, Australia; and founding coordinator of ZEMCH Network. Noguchi's texts are essential literature dealing with the ZEMCH term. The interview was centred on theoretical aspects related to the construction of the ZEMCH term. The interview took place as part of the fieldwork developed in Japan. It was recorded (audio) and transcribed. The information gathered from this interview was used to analyse theoretical concepts.

Ben Murphy— Framework Operations Coordinator of Robertson Construction Group. For this interview, Murphy responded to a series of questions through email correspondence. This correspondence was complemented with conversations aiming at responding to the relevant questions in greater detail. The interview centred on aspects related to the procurement position and process of Robertson Construction group concerning the housing context in the UK.

Mike Cruickshank— Sales director at Scotframe Timber Engineering. The interview focused on aspects of production and market research. The interview was recorded (audio) and transcribed. The information gathered from this interview was used to complement the information gathered from the fieldwork visit to Scotframe facilities.

Samuel Gonçalves— Founder of SUMMARY Architects in Porto, Portugal, with professional experience in ELEMENTAL studio and a guest participant of 'La Biennale di Venezia - 15th International Architecture Exhibition' in 2016. The interview focused on the interest of architects in prefabrication and industrialisation of the housing process. The interview was recorded (audio) and transcribed. The information gathered from this interview was used to analyse the architectural stand towards prefabrication.

Graham Shawcross— British architect with expertise in housing R&D, Computer-Aided Design Programming and latterly the design of secondary and further education establishments. Mr Shawcross also worked on the development of automated systems for social housing programmes in the UK for the 'Ministry of Housing' in the late 1960s and 1970s. The interview centred on the interests and ambitions of the housing providers in the UK regarding prefabrication and pre-design. The interview was recorded (audio) and transcribed. The information gathered from this interview was used to compare the ambitions and expectations of prefabricated and automated constructions systems with the current housing industry in the UK.

The interviews to Ben Murphy and Mike Cruickshank were related to data obtained from housebuilders in Japan and the UK. Interviews to Masa Noguchi, Samuel Gonçalves and Graham Shawcross were developed from a neutral perspective. These later interviews provided qualitative data in relation to the perspective of different agents involved in the housing process. It was used in Chapter 3 to specify the points were literature review showed a gap in knowledge or contrasting perspectives.

The fieldwork sites were carefully selected to provide comparable parameters for the research. The companies were selected for their capacity to produce variable outcomes and their focus on energy-efficiency. The research/innovation centres, construction fairs and housing prototypes were selected to provide an updated comparison of the products currently available on the market, as well as a level of scientific and technological standards in both contexts. The following table describes all the sites, companies and facilities visited during the fieldwork, not all sites were used in the final data matrices, neither in the composition of the thesis (Table 2).

Table 2. Fieldwork sites and description.

	Date	***Company / Organisation***	***Location***	***Type of facility***	***Name / Description***
Japan	May 2016	*Taisei Corporation*	Yokohama	Building prototype	Taisei Corporation Technology Centre / Zero energy office building
	May 2016	*The University of Tokyo*	Tokyo	Building prototype	COMMA (COMfort MAnagement) House / Zero energy house
	May 2016	*Sekisui House*	Kanto, Koga, Ibaraki	Building prototypes	Eco First Park / Zero energy, zero carbon and passive houses

				Manufacturing facilities	Kanto manufacturing and recycling facilities
				Housing park	Kanto housing park / Showhouses and technical showrooms
			Kizugawa, Kyoto	Information centre	House Creation Experience Museum / Selling and co-design centre
	May 2016	*Sekisui (Heim) Chemical*	Toyohashi	Manufacturing facilities	Aichi Plant
				Showhouse and selling centre	S-Square / Selling centre and showhouse in Aichi Plant
	May 2016	*Misawa Homes*	Konan	Manufacturing facilities	Nagoya Plant
	May 2016	*Daiwa House*	Nara	Museum	D'Museum / Museum of Daiwa's history and vernacular architecture
				Information centre	Techno Gallery / Technical showrooms
				Research and development centre	Central Research Laboratory / Test of houses
	May 2016	*LIXIL*	Osaka	Selling centre	Store and showroom
UK	March 2016	*Carbon Dynamic*	Invergordon, Scotland	Manufacturing facilities	Assembly facilities
	March 2017	*Ecobuilt*	London, England	Construction fair	Construction fair focused on sustainable products
	March 2017	*Scotframe*	Cumbernauld, Scotland	Manufacturing facilities	Scotframe's Cumbernauld Timber Engineering facilities
				Design and engineering offices	Central design office
				Showroom	Display of features
	April 2017	*Echo Living*	Kilsyth, Scotland	Construction site	Burnhead Bothies / Prefabricated off-grid Holiday cottage
	June 2017	*Robertson*	Seaham, England	Manufacturing facilities	Robertson Timber Engineering facilities
	Sept 2017	*BRE—Building Research Establishment*	Ravenscraig, Scotland	Show villa	Ravenscraig Innovation Park / Passive Haus and low energy housing prototypes
	Dec 2017	*Construction Scotland Innovation Centre*	Hamilton, Scotland	Manufacturing facilities	CLT press, Insulation and timber frame machinery
	April 2018			Workshop	Presentation of 'Modernise or Die' report & Technology display

The material collected from the fieldwork consisted of photographs, video and audio recordings, pamphlets, brochures, technical guides, recorded interviews and personal notes. This material was then coded to serve as useful data for the development of the research argument. The coding process is explained further in the ‘Coding’ section of this chapter. The data collected was categorised and analysed to find patterns and then cross-validated with theories built form using grounded theory methods (Eaves, 2001:655).

Grounded Theory

This research understands 'grounded theory' as the research strategy used to generate theory derived from the process of systematically gathering and analysing data (Wisker, 2001:187). Grounded theory uses systematic data collection and comparative analysis procedures to identify the core patterns in the data collected and verify theoretical assumptions (Eaves, 2001:655; Dey, 1999:1-2). It is an approach that relies on fieldwork and on the ability to generate theory from data (Denscombe, 2007:92; Strauss & Corbin, 1998:8,12; Walsh et al., 2015:582).

Grounded theory was a research approach and method that fitted with the needs of the research. The aim of the research was to find the relationships between mass customisation and the production and performance of zero energy houses; in other words, to build a theoretical argument (theory). Grounded theory fosters theory building using data and information gathered from mixed research methods as the ones used in this research: literature review and fieldwork (Walsh, 2015:531). Also, it was compatible with the data collected from the fieldwork as it works with the combination of qualitative and quantitative data obtained from the fieldwork (Strauss & Corbin, 1998:8,12).

The approach to grounded theory came as a consequence of the research process. It was not until the fulfilment of the initial literature review and collection of data from the fieldwork in Japan, that the need of theory building concerning the relationship of mass customisation and the production of zero energy houses was realised. As explained in Chapter 3, this mentioned relationship has not been defined in the literature, in which the conceptualisation of the ZEMCH word comes as the closest reference; however it also lacks a reliable definition. Moreover, it was discovered that the conceptualisation of the

ZEMCH term was dictated as a hypothesis of observations on pragmatic practices, precisely in the manufactured housing context of Japan (Noguchi et al., 2016b:339; Noguchi, 2013b:166-167; Noguchi & Hadjri, 2010:898,903). Therefore, building the definition of ZEMCH was taken as a step towards the research goal and the answering of the research questions.

Initially, it was expected that all data obtained from fieldwork to have quantitative qualities, excluding interviews; however, the material provided from the sites and companies, such as brochures, portfolios and other marketing material, revealed qualitative data that was very useful for understanding the whole housing system, and thus, answer the research questions more appropriately. Thus, despite the fieldwork and literature review of secondary sources was focused on the extract of quantitative data, it was realised that qualitative data had an important role in developing the research argument. This research, as pragmatic and systemic research, involved empiric processes, in which the use of grounded theory was determined by the self-development of the research, justified by Isabelle Walsh (2015:551) as,

> *'...the most innovative quantitative studies result from first letting the data talk, and then laying down hypotheses. Openly applying a Grounded Theory framework with quantitative data might free quantitative researchers to be more open about the way they write up their research, and bring out the creative, theory-building aspect of their work. As for mixed design, Grounded Theory might be the path to enhanced formal theoretical development. ...This meets with Grounded Theory and its emphasis on empirical research as a basis for theory development and practical value.'*

Accordingly, grounded theory was used as a research method rather than a guiding methodology or research paradigm. It was linked to the processes of analysis of data and writing of the thesis. The structure of the thesis was designed over the type of material used.

Chapter 3 uses qualitative data obtained from the literature review and interviews. This chapter is mainly composed of information gathered from the literature. However, the structure and sequence of the chapter were developed in accordance with information collected from the interview to Masa Noguchi– figure recognised as the mind behind rationalising and arranging the ZEMCH terms together. It was essential to understand Noguchi's position and rationale not depicted in literature. In the interview, Noguchi described what the terms of mass customisation, zero energy and home mean from his perspective. This information complemented the literature review were these definitions (from a ZEMCH Network perspective) were missing. Noguchi's interview was crucial to the conception of this chapter, and the research in general.

The additional interviews presented in this chapter— Samuel Gonçalves & Graham Shawcross— justified the research stand on particular points where literature sources were limited, ambiguous or contradicting. Gonçalves interview confirmed the position of the architectural practice towards customisation, as an architect that promotes the used of prefabricated construction components; while Shawcross interview confirmed the need for customisation in housing from the perspective of designers working for the government, which have a strong attachment to mass housing and prefabrication.

Chapters 4 and 5 are built using only data from the literature review. Chapter 4 uses quantitative data only, while Chapter 5 uses both, qualitative and quantitative data. It was significant to keep these chapters independent from each other to mark a differentiation between the type of data collected, besides they being considered independent topics by the author. The methods used to collect and represent the information were however homogenous in the whole research, consisting of data matrices and information comparative tables.

Chapter 6 and 7 use quantitative and qualitative data obtained only from fieldwork. Most of the information was obtained from primary sources, particularly of visits to the facilities. These chapters are highly descriptive. However, their conclusions present theoretical arguments developed following Grounded Theory methods, where theory is built through the data collected from the fieldwork. Chapter 6 includes information from a series of interviews and surveys to Ben Murphy. It was used to confirm the resistant position of housebuilders in the housing process that literature points as conflicting for achieving sustainable housing. In Chapter 7, the interview with Mike Cruickshank was used to understand the position of the housebuilders regarding the lack of inclusion of energy-efficient mechanical systems and renewables in their houses, information which could not be grasped from visiting their facilities, as it is unrelated to production processes.

It was important to keep chapters 6 and 7 independent from each other as the theoretical arguments presented in each are very different. Chapter 6 conclusion focused on the feasibility of mass customisation production processes based on quantitative data. Chapter 7 focused on the lack of design and marketing strategies in the UK context related to the production of zero energy houses based on qualitative data. The arguments were displayed clearer if the chapters were structured individually. Also, it helped to manage the information and clarify where aa type of data was used.

Integration of methods through triangulation

This research followed triangulation methodology principles. For triangulation, the multiple methods used in the research can be used separately or integrated; which means that the methods can be merged at any point between conceptualisation and across all phases of the research (Moran-Ellis et al., 2006:54; Strauss & Corbin, 1998:13).

The research methods were integrated based on triangulation principles at two stages of the research process. (1) First, on how the data was collected using data matrices developed in spreadsheets; and (2) second, on how the data was organised and display in the body of the thesis, which happened during the writing process.

(1) *The collection of data*– The data matrices used to manage and compare the data collected included data from multiple sources. This research did not isolate information regarding its source. Primary data was mixed with secondary sources and information obtained from the literature review, particularly from scientific journals. Examples of these data matrices are displayed in the thesis' appendices (Full tables and matrices of data).

(2) *Writing process*– Once the data matrices were filled to justify arguments, they were formatted to be integrated into the body of the thesis. Redundant or

misleading information was not considered. The matrices were transformed into the multiple tables observed in the whole thesis.

The arguments presented in Chapters 3, 4 and 5 are described through literature references; however, these were only developed to completion after the data matrices were formed. The process of integration of methods and data was not linear but circular. First, some literature review was developed. Then fieldwork to obtain new data related to that information. Then, the data matrices were arranged. Then, some more literature was consulted to complement the matrices. Then, some theory was built from the data collected, including interviews. This circular process was repeated several times until the arguments were fully justified and developed.

It is clear how the methods were integrated on how Chapter 3 is structured and written. For that chapter, first, some literature was consulted, focusing on texts developed by the ZEMCH Network. It was discovered that the ZEMCH term was not defined; and therefore, some primary information was required. The interview to Noguchi from fieldwork was used at this point. Then, the references previously collected were mixed with the primary information. Then, more literature review was developed the topics of the chapter. Additional interviews with Shawcross and Gonçalves were used to justify particular points. Finally, a conclusive argument was built from the various data and material included in the chapter following grounded theory principles.

The other chapters followed a similar integration process but adapted to the characteristics of the material and data used for each chapter.

Unit of analysis

This research understands the 'unit of analysis' as the major entity analysed in a study, as the unit of generalisation or sampling (Keller, 2010:1585-1586).

In Japan, the housing manufacturers of mass customisable houses were selected as the unit of analysis. In the UK, the speculative housing developers, housing manufacturers and manufacturers of housing components were selected as the unit of analysis.

The Japanese housing manufacturers were selected as the unit of analysis because they lead the production of zero energy mass customisable houses, as explained in chapter 3 (Noguchi et al., 2016b:339; Noguchi, 2013b:166-167; Noguchi & Hadjri, 2010:898,901-903; Naim & Barlow, 2003:601; Johnson, 2007:27; Zero Carbon Hub, 2009:30-31; Bardakci & Whitelock, 2003:471; Davis, 1987:158; Knaack et al, 2012:54-55; Piroozfar & Piller, 2013:7; Iwashita, 2001:295). Speculative housing developers were selected because these are the dominant housing providers in the UK. House manufacturers and manufacturers of housing components were selected because these have the production capacity to implement mass customisation systems, as explained in chapter 6 (Barlow et al., 2003:135; Barlow & Ozaki, 2005:13,10,25). The following table presents the companies selected as the unit of analysis (Table 3).

Table 3. Unit of analysis, selection of housebuilders and house manufacturers.

Context	***Company name***	***Type***	***Fieldwork***	***Literature Review***	***Statistical Sources***	***Selected in comparison***
Japan	*Sekisui House*	Mass customisation house manufacturer	X	X	X	X
Japan	*Daiwa House*	Mass customisation house manufacturer	X	X	X	X
Japan	*Sekisui (Heim) Chemical*	Mass customisation house manufacturer	X	X	X	X

Japan	*Toyota Home*	Mass customisation house manufacturer		X		
Japan	*Taisei Corporation*	Contractor	X			
Japan	*Misawa Homes*	Mass customisation house manufacturer	X		X	
Japan	*LIXIL*	Supplier	X			
Japan	*Tokyo University*	Research institution	X			
UK	*Facit Homes*	Contractor		X		
UK	*Carbon Dynamic*	House manufacturer	X	X	X	X
UK	*Echo Living*	Bespoke service	X			
UK	*Scotframe*	House manufacturer, manufacturer of components	X	X	X	X
UK	*Robertson Group*	Manufacturer of components, contractor and housing developer	X	X	X	X
UK	*Barratt Homes*	Housing developer		X	X	
UK	*Persimmon*	Housing developer		X	X	
UK	*Taylor Wimpey*	Housing developer		X	X	

The use of secondary sources was essential for understanding the unit of analysis (housebuilders). The material collected from fieldwork contained crucial information and data not present in other sources, because companies tend to reserve financial data to the general public, as it is not in their marketing purposes. However, companies are forced to deliver financial reports annually; and depending on their scale, the information has to be more detailed. Therefore, statistical sources were used to gather additional data of the unit of analysis, to complement the data obtained from the fieldwork. The statistical data was collected from annual reports published by companies (including video recordings of the annual reports); open sources of data created by organisations dedicated to the collection and publication of statistical data, like ‘Companies House’ or ‘Trading Economies’; academic journals; and selected literature.

Data collection methods

This research understands ‘collection methods’ as the techniques used to extract data from primary and secondary sources to find answers to the research problem, test the hypothesis and evaluate the research findings (Walsh et al. 2015:584; Walsh, 2015:533-534). The research methods used in this research appropriate to extract data from the sources selected were:

- ***Direct observations*** *[qualitative and quantitative]*– Observation refers to the systematic data collection approach that, as the name implies, is a way of collecting data through observation. Observation data collection method is a participatory study. The researchers needed to have direct access to the research phenomena. Data was collected through recordings (photo and video) and personal notes. An unstructured observation strategy was used in this research because the researcher was limited to whatever materials/data to which the companies were willing to provide access. Structured observations would conflict with the limited access, while flexible strategies adapted to the material offered by the companies under study.

- ***Documents and reports review*** *[qualitative and quantitative]*– Document review refers to the way of collecting data by reviewing existing documents. The documents are internal to an organisation, such as brochures, or external, as reports (CDC, 2009:1). This research used this technique to gather background information and acquire information that complemented data collected from the fieldwork.

- ***Case studies*** *[qualitative]*– Case studies are empirical inquiries that investigate a contemporary phenomenon within its real-life context. Multiple sources of evidence are used to extract data when the boundaries between phenomenon and context are not evident (Zainal, 2007:1-2). Case studies were used to examine in detail the housing contexts of Japan and the UK without dealing with the full spectrum, but a sample to average. The case studies were selected to provide comparable data, in terms of historic time framing, housing purpose and relation to mass production.

- ***Interviews** [qualitative]*– This research understands interviews as conversations that have the purpose of gathering descriptions of a topic or subject in order to interpret a phenomenon from the perspective of the interviewee (Alshenqeeti, 2014:40). A series of semi-structured interviews were developed in this research. These interviews gather the perspective of individuals on the topics in question, strengthening the research through alternative or detailed provision of data (Kolb, 2012:84).

The data was collected as follows (Table 4).

Table 4. Details of data collected.

Data	*Material Collected*	*Collection Method*	*Source*	*Category*	*Method group*	*Subject*	*Context*
Production process— machinery, construction system, supply chain, engineering, design process	Photos, videos and personal notes	Direct observation	*Fieldwork*— companies' facilities, factory visit	Primary	Quantitative and qualitative	House manufacturers	UK and Japan
Production process— machinery, construction system, supply chain	Diagrams and technical information	Documents and records review	Literature	Secondary	Quantitative and qualitative	House manufacturers	UK and Japan
Production process— machinery, construction system	Technical information	Interview (alternative) — personal contact	*Fieldwork*— direct contact (email) with technicians	Secondary	Quantitative and qualitative	Research centre	UK
Selling process— scale, marketing techniques, investment	Brochures, photos, videos and personal notes	Direct observation	*Fieldwork*— companies' facilities, selling centres, show	Primary	Quantitative and qualitative	House manufacturers, housebuilders	UK and Japan

			homes/villas, research centres				
Selling process— scale, marketing techniques	Statistical information, theoretical background	Documents and records review	Literature, journals, corporative material (catalogues, brochures)	Secondary	Quantitative and qualitative	House manufacturers, housebuilders	UK and Japan
Background context— historical background	Photos, videos and personal notes	Direct observation	*Fieldwork*— companies' facilities	Primary	Qualitative	House manufacturers, housebuilders	Japan
Background context— historical background	Theoretical background	Documents and records review	Literature, journals, corporative material (websites)	Secondary	Qualitative	House manufacturers, housebuilders	UK and Japan
Economies, production scales and capacities	Statistical information	Direct observation	*Fieldwork*— companies' facilities, selling centres, factories	Primary	Quantitative	House manufacturers, housebuilders	UK and Japan
Economies, production scales and capacities	Statistical information	Documents and records review	Literature, journals, corporative material (catalogues, brochures, website, reports)	Secondary	Quantitative	House manufacturers, housebuilders	UK and Japan
Contextual statistical information	Statistical information	Documents and records review	Literature, journals, statistical sources	Secondary	Quantitative	Contextual situation	UK and Japan
Contextual statistical information	Statistical information	Documents and records review	Literature, journals, statistical sources, real estate brochures	Secondary	Quantitative and qualitative	Housing market	UK and Japan
Description of procurement processes that dominate the market	Photos and personal notes	Case study	Fieldwork— visit housing developments	Primary	Qualitative	Housing market	UK
Description of procurement processes that dominate the market	Visual material, diagrams, theoretical background	Case study	Literature, journals, statistical sources, real estate brochures	Secondary	Quantitative and qualitative	Housing market	UK and Japan
Interpretation of a phenomenon	Recording	Interview	*Masa Noguchi*— ZEMCH Network founder	Primary	Qualitative	mass customisation, ZEMCH	Neutral
Interpretation of a phenomenon	Written interview	Interview	*Ben Murphy*— Framework Operations Coordinator of Robertson Construction Group.	Primary	Qualitative	Housing manufacturing and procurement	UK
Interpretation of a phenomenon	Recording	Interview	*Mike Cruickshank* — Sales director at Scotframe Timber Engineering	Primary	Qualitative	Housing manufacturing and selling criteria	UK
Interpretation of a phenomenon	Recording	Interview	*Samuel Gonçalves*— Founder of SUMMARY Architects	Primary	Qualitative	Architectural design through prefabrication	Neutral
Interpretation of a phenomenon	Recording	Interview	*Graham Shawcross*— British architect	Primary	Qualitative	Historical data of housing	UK

			with expertise in housing R&D				
Theoretical background	Theoretical standings	Documents and records review	Literature and journals	Secondary	Qualitative	mass customisation, energy efficiency, housing-related	Neutral
Historical precedents	Historic narrative	Documents and records review	Literature and journals	Secondary	Qualitative	Construction systems, housing-related	Neutral

The data was archived and collected using different methods appropriate to the nature of the material. Most of the data was taken from the physical material, coded and archived in virtual files. Quantitative data was coded into numeric forms and arranged into spreadsheet tables, named as data matrices. The collection of qualitative data required varied coding processes, as the information needed had different forms; texts, diagrams, maps, photographs, images, and sometimes it was first translated as it was in the Japanese language. Thus, different coding systems were used.

Coding

This research understands 'coding' as the process of analysing data that presents a complete picture of the information gathered during the data collection process (Kolb, 2012:84). It refers to the processes developed to convert the material collected into useful and comparable data for the research.

This research used a coding strategy divided into three stages:

(1) *Open coding*— refers to the collection of data using predesigned coding matrixes. It concretively refers to the process of how the data was captured directly from fieldwork (O'Cathain et al., 2010:2). Spreadsheet tables were designed to be printed and carried into the fieldwork sites. These tables consisted of columns of

categories of potential data that could be obtained from the housebuilder's facilities visits. These tables were designed based on the data presented in the literature reviewed, which were used to capture quantitative data. Google Sheets– equivalent to Excel– was used as the capturing and archiving tool. It was selected because it allowed extensive customisation, and the scale of data collected did not require complex calculation sheets. These tables have been attached to the thesis' appendices.

This stage also includes the capture of interviews. The interviews were designed to extract qualitative data. The interview's questions were established in accordance with the literature review progress; meaning that the questions were enquiring about the aspects where the literature did not show a clear tendency or presented knowledge gaps. These were also designed to extract information to complete missing data from the data matrices taken to fieldwork sites. The interviews were semi-structured which means there were a set of questions designed to be asked, but these were modified, added or suppressed depending on the interviewees' responds. The audio of the interviews was recorded, and then was transcripted to the computer. Google Docs– equivalent to Word– was used as the software to archive and transcript-in the interviews. This research contemplates only five interviews, which all of them vary from each other. It was priorly considered that the answers of the interviewees will not provide comparable, either correlatable information. Each interview was designed individually, and progressively from one another; and distributed during the whole lapse of the research. The interviews were not established for those purposes. Therefore, qualitative software, like Atlas or NVivo, were not required.

The full interviews are presented in the appendices of the thesis. The particular format of the interviews, meaning crossing out of questions, relates to the modifications to the original design of the interviews.

(2) *Axial coding*— refers to the categorising of data through comparative tables. This phase contemplates collection also secondary sources. The collected in the open coding phase was rearranged and organised in new data matrices. This phase was developed to generate matrices more closely related to the research goals. The matrices were refined regarding the development of the literature review; and in accordance with the type of data collected.

In this phase, the data was collected from primary and secondary sources, as well as from literature review. Secondary sources refer to direct material produced by the unit of analysis collected from open sources, including pamphlets, brochures, websites, books, financial and sustainability reports. It included the translation of prime material from Japanese.

Also, it included an analytic reading of the interviews. In this phase, the transcripts of the interviews formatted to highlight useful information, phrases and keywords. It also involved the addition of personal notes to help to link the interviews to the research argument.

(3) *Selective coding*— refers to the subtraction and cross-validation of data. This phase connected the data matrices with the writing and development of the research argument. It concretively refers to the process of transforming data

matrices into useful information for the formatting of the thesis (Kolb, 2012:84; Eaves, 2001:660; Walsh et al., 2015:593-594). In this phase, the tables of the data matrices were summarised and formatted to display only the information needed to support the written argument of the thesis. It included the development of diagrams, mental maps, collages and sequence of images as representation techniques. These diagrams were refined several times in relation to the development of the research. Some previous diagrams are attached in the appendices. This phase included the selection and extraction of phrases from the interviews into the thesis.

Data analysis techniques

'Data analysis' refers to the procedures of inspecting, cleansing, transforming, and modelling data; this includes the techniques for interpreting the results of such procedures, ways of planning the gathering of data to make its analysis useful, precise and accurate (Tukey, 1961:2). Likewise, this research understands 'analysis techniques' as those methods and instruments that translate the data collected into useful information for the construction of the research argument (Walsh et al. 2015:584).

The analysis techniques used in this research were (1) comparative tables, (2) translation of original material and (3) visual representations.

(1) *Comparative tables*— Comparative tables were used as a technique to compress and compare data. They were developed using spreadsheet software. The comparative tables were used to compare quantitative and qualitative data. The

tables were structured from common criteria shared by the data. The comparative tables worked as the coding filter and archive, where data collected in the tables was codified to a homogenous language in terms of measurement units, currency and language. The systematic process of arranging, shifting and coding the data is an integral part of the analysis process (Kolb, 2012:84).

(2) *Translation of prime material*— The material collected during the fieldwork in Japan was translated into English with the assistance of a professional translator. The materials translated were brochures, catalogues and technical pamphlets provided by the companies under study. Brochures were sent to the translator, who returned detailed transcripts of selected sections of all brochures. Additional translations of keywords or small pictographic symbols were done using translation software. Translations attached to the appendices.

(3) *Visual representations*— The research process included the creation of graphical information, such as diagrams, charts, timelines and digital bibliographic referencing. These techniques were used to display data and information in formats that help the reader to understand the thesis' arguments (Lucas, 2016:179). Visual representations were initially used to collect, organise and link the material collected, including bibliographical texts, images and statistical information.

Structuring of the thesis

The structuring of the thesis, meaning the division of the chapters, was guided by the topics described in each chapter and by the source of the material used and type of data (qualitative or quantitative) in them; both criterion equally. Accordingly, Chapters 4 and 5 present only information from the literature review; while Chapters 6 and 7 information from fieldwork. The characteristics of each chapter have been described in this chapter and the previous one.

Research limitations

This research was framed to the UK and Japan; this limitation was established concerning the rationale of studies and as an insight into the literature review. The conclusions and suggestions obtained in this research might not apply to contexts beyond the UK.

This research considers a selective range of companies in both contexts. Some conclusions might be different if more, or different, companies were analysed. Moreover, the information and data collected from primary sources were filtered by the companies, which might restrict the information provided for protecting their unique production processes.

The research only contemplates a short range of interviews. These were not considered the main source of data. They were used to justify particular points where other research methods were not providing full information, following the triangulation methodology. However, there is the possibility that the data collected from the interviews provide a one-sided perspective, related to the interviewee's self-understanding of the phenomena in question.

Further research

Industrialised housing is a common practice in multiple places. As examples; countries in Latin America have used construction systems based on small scale prefabricated components, as 'joist and vault', for the construction of mass housing developments, while having high traditions of self-construction that with time results in highly customised outcomes. Also, in Nordic and Soviet countries industrialised construction has played an important role in modern and recent history.

This research was framed to the UK because it is a context that has stated an interest in applying industrialised construction processes to achieve higher levels of energy efficiency (reduction of carbon emissions), or as referred locally applying 'Modern Methods of Construction' (Farmer, 2016:20,62; MACE, 2018:6,14; Zero Carbon Hub, 2013:1; Pan et al., 2007:12; Pitts, 2017:9,15).

Most of the companies analysed were founded in Scotland, which has a stronger usage of industrialised methods of construction than the rest of the UK, particularly of timber. In Scotland, 66% of new dwellings are built using factory-assembled timber components, while this accounts for only 27% in England (Shafik & Martin, 2006:82; Hairstans & Sanna, 2017:224-251). There is a potential of reframing the research into the Scottish context, focusing on how the geo-climatic conditions, policies and manufacturing traditions relate to the application of mass customisation and sustainable housing.

If the studies are extended beyond the UK, there is an interest in understanding how companies and architectural firms in those contexts are approaching manufacturing processes in relation to the production of sustainable and customisable housing.

Understanding their particularities would allow the triangulation of the Japanese, UK and this additional context to identify the appropriate ways and mediums to apply co-design, marketing and selling strategies to impulse the production of sustainable houses adequate to each context.

It also appears crucial to identify which is the role of the architect in the whole design, production and selling process of mass custom houses. Not only from the research and practice perspectives, but on how co-design strategies could positively affect architectural pedagogy. Therefore, this research could expand and study the approaches to co-design at architectural education institutions.

Conclusion

This chapter describes the methodology, research methods, timings, material and strategies used in the development of this research. It also justifies the selection and use of these methods with the topic of study.

This research opted for triangulation of mixed methods as a methodology and methodological paradigm because it was a coherent way to relate a system (housing) to the research questions and objectives focused on sustainability. The research methods– literature review, fieldwork and grounded theory– were selected to correspond to the type of material selected. Fieldwork was essential to collect primary data. Literature review was required to fulfil academic rigour, besides being a very effective research method. Grounded theory was a key method, not only to organise and analyse qualitative and quantitative data, but to assist on the triangulation of the methods and the writing of the research argument.

The research progress followed an intuitive and pragmatic form. Research processes happened simultaneously or parallel to each other. The unit of analysis, collection methods, design of data matrices, interviews and coding systems adapted to the progress and research insights. The material collected from the fieldwork varied and, sometimes, unexpected. The coding systems and collection methods required to adapt to the material. The following table resumes the research process, research procedures and the reason for choosing them (Table 5).

Table 5. Research methodology brief table.

Research process	***Selected type, research tools or procedures***	***Reasons for choice***
Research methodology	*Triangulation*— process and combination of research methods and techniques needed to solve research.	An effective method to cross-validate the findings and overcome the limitations of each of the collection methods used in this research.
The philosophy of the research	*Pragmatic approach*— analysis and solving of a problem, free of constraints imposed by research traditions.	The use of multiple approaches helps to eliminate the potential biases presented by the research.
Research approach	*Mixed Methods*— inquiry involving collecting both quantitative and qualitative data, integrating the two forms of data, and using distinct designs that involve philosophical assumptions.	Adequate to cope with the variety in contexts contemplated in this research, which required the use of different data collection methods
Research strategy	*Multiple strategies: literature review, fieldwork and grounded theory.*	Literature review, fieldwork and grounded theory were selected as research strategies for their effectiveness and compatibility with pragmatism, triangulation and each other.
Unit of analysis	*The Japanese housing manufacturers* (mass custom/self-built market)*, the UK real estate and the UK manufacturing sector for housing components.*	The reputation of Japanese housing manufacturers in terms of mass customisation and energy efficiency. UK real estate production capacity and the similarity between the manufacturing procedures in the UK and Japan.
Data collection methods	*Direct observations, documents and reports, case studies, and interviews*	Techniques appropriate for extracting data from the sources selected.
Coding	*Open coding, axial coding and selective coding*	Effective techniques concerning the data collected and the research methodology selected.
Data analysis techniques	*Comparative tables, translation of original material and visual representations.*	

The research methodology was useful and allowed an efficient build of theoretical arguments about the relationships between mass customisation and energy efficiency, which runs by the research objectives. The research outcomes are limited in detail of technical application or engineering particularities. However, the goal of the research was to explain the systemic problems present in the production of sustainable housing in the UK and provide pragmatic solutions based on direct observations to the current practices.

Chapter 3

From ZEMCH to Mass Customisation for Zero Energy Houses

This chapter focus on defining the acronym ZEMCH, which currently stands for Zero Energy Mass Custom Home. This chapter defines ZEMCH as a single concept rather than as a contraction of different terms. It presents existing research on the topic and explains relationships between the goal of 'zero energy' and processes of 'mass customisation'. It is important that ZEMCH is understood from first principles, especially in relation to thermodynamics as well as its historical development. The chapter's objective is to define zero energy and mass customisation in such a way as to demonstrate strong links between two phenomena that are often part of different research domains. The argument of this chapter was composed using texts produced by the ZEMCH Network, an interview with Masa Noguchi, related literature review; and exemplified through a series of examples in practice.

Introduction

This research proposes the use of mass customisation to positively impact the production of zero energy dwellings. Accordingly, this chapter validates the relationship between mass customisation and the production of zero energy dwellings by corroborating its theoretical compatibility.

This conceptual marriage between mass customisation and zero energy dwellings was initially suggested as ZEMCH— the acronym of Zero Energy Mass Custom Homes. In 2010, academics Masa Noguchi and Haşim Altan used the acronym ZEMCH for the first time to name a technical tour to facilities of Japanese house manufacturers. The tour was previously named 'Zero Energy Mass Custom Homes Mission to Japan' and was eventually renamed as 'ZEMCH Mission to Japan' (Noguchi interview; personal information, May 2016). The acronym was also used to name an academic network— the

ZEMCH Network— and the conferences organised by this. The ZEMCH term has been used to entitle different publications, including a book entitled 'ZEMCH: Towards the Delivery of Zero Energy Mass Homes' six conference proceedings and special editions of journals.

However, the term ZEMCH has not yet been defined. Therefore, this chapter proposes possible definitions of ZEMCH by merging definitions of mass customisation and net-zero energy houses.

This chapter also presents definitions of the concepts related to zero energy and mass customisation. In terms of zero energy, the concepts defined in this chapter are zero energy building, energy balance, metric or balancing indicators, balancing period, balance type, energy usage coverage, generation type, generation location, grid connection, spatial boundary. In terms of net-zero energy, the concepts defined in this chapter are zero site energy, zero source energy, zero energy emissions and zero energy costs. In terms of mass customisation, the concepts defined in this chapter are mass production, craftsman production, mass customisation, solution space, robust process design, choice navigation, mass customisation enablers and customer decoupling point. This chapter describes the difference between Home and similar terms.

The terms in concern are described using companies and historical events as examples. This chapter concludes by proposing definitions for ZEMCH, explaining how these relate to housing practice and sustainability.

ZEMCH as ‘Zero Energy Mass Custom Homes’

ZEMCH is a term constituted by five different words: zero, energy, mass, custom and homes. The ZEMCH Network coined this concept ‘*with the aim to enhance industry-academia R&D [Research and Development] collaborations on the delivery of zero energy mass custom homes’* (Noguchi, 2016:v-vii; zemch.org).

Mass customisation and zero energy buildings are known concepts that have their theoretical definitions and are commonly used in practice. ZEMCH, as a term, has only been employed to badge conferences, technical tours, workshops, networks and postgraduate programmes. However, the significance of deploying the ZEMCH term relies on a declared relationship between mass customisation and zero energy dwellings; or framed more straightforwardly, as the production of zero energy dwellings through processes of mass customisation.

The definition of ZEMCH is implied from the words that lie behind the acronym and also the context in which the term is used. However, such an assumed understand does not necessarily convey the meaning intended by the ZEMCH Network as originators of the term. The ZEMCH Network (zemch.org) defines ZEMCH as:

> *‘[Concept that aims] to tackle issues arising in the delivery of socially, economically and environmentally sustainable built environments in developed and developing countries, which accommodate people with different socio-economic backgrounds that relate to ages and abilities.’*

This definition provided by the ZEMCH Network relates to the deployment of the term ‘sustainable development’ as defined in ‘Our Common Future’— the foundational document developed by the World Commission on Environment and Development (WCED, 1987:43).

> *'Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. ... Thus the goals of economic and social development must be defined in terms of sustainability in all countries— developed or developing, market-oriented or centrally planned. ...sustainability implies a concern for social equity between generations…'*

The ZEMCH Network definition is certainly influenced by the objectives of 'Our Common Future', which reflects the Network's stance towards sustainable development principles. However, as for as the ZEMCH Network was concerned, at the time the constituent terms, 'zero energy' and 'mass customisation' were overlooked.

Accordingly, Our Common Future does mention the term 'energy', defining it as an *'essential human need… necessary for daily survival …[that] provides 'essential services' for human life— heat for warmth, cooking and manufacturing…'*. This definition of energy is somehow related to the domestic space by referring to *'heating'* and *'cooking',* or to the construction process by mentioning *'manufacturing'* (WCED, 1987:55,168). However, it does not provide a definition that can be measurably associated with production processes such as mass customisation because it focuses on political ambitions (Grønning, 2017:27).

In a personal interview (2016), Noguchi— ZEMCH Network founding coordinator and identified as the author of the texts in concern— explains how he understands the relationship of mass customisation and zero energy.

'... energy is energy, is the same everywhere, a kilowatt is a kilowatt. So, zero energy is simple. Zero energy needs to be a standard. While zero energy needs to be a standard, mass customisation is a social need. Thus, ZEMCH is social, economic and environmental sustainability; not only environmental sustainability. All things come together as ZEMCH.'

In contrast to the ZEMCH Network definition, Noguchi does refer to both concepts— zero energy and mass customisation— implying the existence of a relationship among them. The definitions of zero energy and mass customisation remain unrevealed; however, there is a notion of considering them as accepted concepts. Noguchi particularly refers to energy as a universally understandable measurement.

The ZE— Zero energy

In physics, energy refers to the capacity of a system to do work. However, energy can be referred to as various settings: the kinetic motion of an object, the potentiality stored by an object's position in a force field (gravitational, electric or magnetic), the elasticity of stretching solid objects, the chemical energy released when a fuel burns, the radiant energy carried by light, and the thermal energy due to an object's temperature (Maclay, 2014:1).

The ambiguity of energy, as considered in physics, does not correspond to Noguchi's assertiveness when setting energy as something quantifiable, *'...a kilowatt is a kilowatt...'*. Noguchi's kilowatt (KW) refers to the standard electrical power measurement used for the operational energy of a dwelling (Srinivasan & Moe, 2015:46). Accordingly, energy, as a KW, is measurable and quantifiable.

However, a literal interpretation of **zero** energy would refer to the absence of energy; which would be a misunderstanding, not only of Noguchi's interpretation but to the building practice (Maclay, 2014:2). Operational energy relates to the energy consumed and produced during the life of the building, like electricity, natural gas, water, steam, human heat or energy conversion from natural resources (Srinivasan & Moe, 2015:46). All buildings are inevitably affected by energy during its operational life; and thus, the conception of a zero energy building is impossible.

Accordingly, 'zero' is a mathematical reference, but not a measurement to quantify energy directly. Thus, the zero energy concept is a balance rather than a limit. The following diagrams exemplify this difference; of zero energy as an unreachable point as it means the absence of energy, and zero energy as a point of reference for the balance of different types of energies (Figs. 2 & 3).

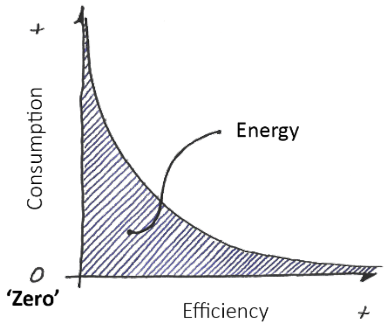

Figure 2. Zero energy saw as a limitation or absence of energy. (diagrams by the Author).

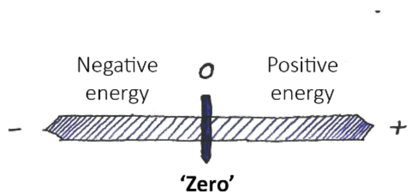

Figure 3. Zero energy saw as a balance.

Noguchi stated that '*zero energy needs to be a standard'* because using standardised concepts and measurements, as zero energy and KW, allow the common understanding of a concept; and thus, of energy calculations, verifications and certifications, such as the 'Passive House' standard (Marszal & Heiselberg, 2009:1; Berry et al., 2014:306; Truong

& Garvie, 2017:215). Energy standards, verifications and certifications are rooted in environmental values. Accordingly, the aim of conceiving zero energy dwellings is to have a low environmental impact by reducing its emissions of CO_2 (Voss & Musall, 2013:6,10; Patterson, 1996:377).

Passive House is a concept pursuing maximum energy efficiency to reduce the dwelling's energy consumption. In contrast, the zero energy concept aims to balance different types of energy to avoid environmental impact. Thus, those energies generated through processes that contribute to CO_2 emissions have a positive value; while the energies produced from carbon-free mediums have a negative value (Passivhaus Trust, 2019:3-4). However, measuring zero energy is not as '*simple'* as Noguchi declares. The factors present in the zero energy balance equation are unspecific, variable and dependant to contextual conditions.

The MC— Mass customisation

Noguchi stated that *'mass customisation is a social need'*. Certainly, customisation is a social need as there is an increasing social demand for diversity and heterogeneity (Toffler, 1970:3; Noguchi et al., 2016a:96; Gilmore & Pine, 1997:91; Da Silveira et al., 2001:1; Piller, 2004:315; Zipkin, 2001:81). However, the 'mass', as in 'mass production', is a production need (Le Corbusier, 1974:210; Gropius, 1956:146; Hounshell, 1984:303,311-315).

Accordingly, Noguchi (2012:iii) refers to mass customisation as *'…a paradigm case of a systems approach to identifying the …wants and needs that should be incorporated into* *the design of end-user products (or homes)'*. Here Noguchi is considering mass customisation from a production stance, indicating that the production side 'should' adequate to the social wants and needs.

Therefore, mass customisation relates to social needs as a production solution to cope with arising conflicting social and economic demands of the built environment (Noguchi, 2016:v). Thus, mass customisation is, in reality, a production solution to cope with social needs. The 'mass' concerns economic and technical (environmental) aspects of production, while the 'customisation' to social concerns of sustainability and customisation.

The H is for…

The 'H' in the ZEMCH Network acronym refers to 'Home'. However, Home implies immaterial aspects that are not strictly attached to buildings (Blunt & Dowling, 2006:22,88). Noguchi declares that even other terms related to home as house or housing are closer to production. Noguchi prefers to use the term home to emphasise its subjectivity, which goes by the ZEMCH Network distinctive ethos and branding.

> *'...I feel really comfortable using Home rather than Housing, or Living Unit, which is more like a product, commercialised product. ...Home is just natural; it is where the family gets together, people come back, children grow; for me it is like a 'nest'. Home sounds 'softer and warmer'; housing and dwelling are more mechanised. That's why ZEMCH uses homes instead of housing. ...There is a common idea of turning a house into a home, I agree with this common sense…'.*

Therefore, according to Noguchi's explanation, it is implied that the ZEMCH concept proposes the use of mass customisation as a production strategy of zero energy houses designed directly from individual wants and needs, as an analogy of the home-making process.

ZEMCH is not a clear concept because of its intrinsic terms; zero energy and mass customisation can have multiple interpretations; understood as an open ended definition. Also, relating a vague term as 'Home' with 'Zero Energy' and 'Mass Customisation' generates semantic conflicts. Thus, this chapter follows by defining zero energy from a physics perspective associated with the building practice, and mass customisation as a business paradigm associated with production, design and manufacturing. This research was framed out of the subjective conditions that using the term Home could dictate[3].

Defining 'Zero Energy'

'Zero energy' is a conceptual term that refers to the balance of energies affecting a system (Berry et al., 2014:305-315; Marszal et al., 2011:971-978; Sartori et al., 2012:220-229; Stene et al., 2018:9).

The zero energy concept is better visualised as the equilibrium of energy flowing in (α) and out (β) a system. For this to be true, the energies need to have different values—

[3] A qualitative exploration of the semantics involving the terms House and Home was developed in relation, or even as an extension, to this research; which consisted of an inquiry on linguistic distinctions, use of the term Home in visual representations and propagandistic or marketing material, such as the ones used to market houses (Appendices additional texts).

positive and *negative*[4]. The zero energy balance is achieved when the value of the positive energy (α) is equal to the value of the negative energy (β) (Fig. 4).

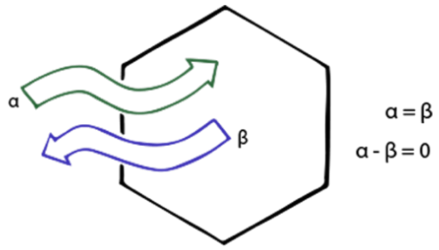

Figure 4. Zero energy on a system with a single energy entity flowing in and an equal is flowing out (diagram by the Author).

For the built environment, zero energy is translated as a building that produces as much energy as it consumes; also known as 'Zero Energy Buildings' (ZEBs) (Voss & Musall, 2013:41; Maclay, 2014:17; Hootman, 2013:4; Williams, 2012:20; Stene et al., 2018:7; Aelenei et al., 2012:34; Torcellini et al., 2006:1; Peterson et al., 2015:1; Athienitis et al., 2010:1).

Energy can allude to the operational energy or embodied energy of a dwelling. 'Operational energy' refers to the amount of energy consumed by a building, independently of the energy used in processes associated with the production, construction or delivery of it. Operational energy is typically referred to the heating, cooling, ventilation, domestic hot water, fixed lighting and plug-loads happening in a dwelling (Sartori et al., 2012:223). In contrast, 'embodied energy' refers to all the energy used during the processes associated with the production of a building, including raw material extraction, manufacturing, procurement, use, maintenance, and end-of-life disposal and recycling. Embodied energy calculations are used to calculate the

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[4] 'Negative' or 'Positive' energies should not be confused with the value of gravitational energies, as referred by Farnes (2018:4) or other theories related to the guild of physics.

environmental impact implied in the construction of buildings and are typically used to make measurements for sustainable certifications (Taylor, 2015:3). Zero energy standards focus on operational energy based on the fact that 80% of the energy is consumed during the operational phase of a dwelling (Williams, 2012:20-21).

Defining a ZEB is complicated because it depends on the interpretation of diverse factors (Maclay, 2014:17; Marszal & Heiselberg, 2009:2; Atkins & Emmanuel, 2012: 183).

The factors determining the definition of a ZEB are (1) energy balance, (2) grid connection, (3) metric or balancing indicators, (4) balancing period, (5) balance type, (6) energy usage coverage, (7) generation type, and (8) spatial boundary and generation location (Berry et al., 2014:306-307; Voss & Musall, 2013:28-35).

(1) Energy balance

Energy balance refers to the balance of energy over a fixed period of time[5]. An exact balance is rare to happen. Buildings are defined by dynamism; so, a point of true energy balance is highly elusive. Besides, zero energy is a concept brought-up as an environmental, political or marketing strategy to reduce energy consumption, not as an obsession of reaching a precise equilibrium (Hootman, 2013:38-39; Sartori, 2012:220; Ares, 2016:13).

Thus, zero energy is what might be called a false equilibrium and should be seen as a threshold, where the total 'negative' energy is equal or higher than the 'positive' one. The

[5] The energy balance could also me measured when the time is matched to the energy balance. However, this criterion works in function to the balance rather than by time; thus, its environmental meaning is uncertain (Voss, 2013:29).

negative and positive connotations are related to the CO_2 emissions of the energy source. The following graphic exemplifies the zero energy threshold as energy generated on-site against energy consumed from the grid. When the energy generated overpass energy consumed represents the negative energy (shaded area) it is considered as part of the zero energy balance (Fig. 5).

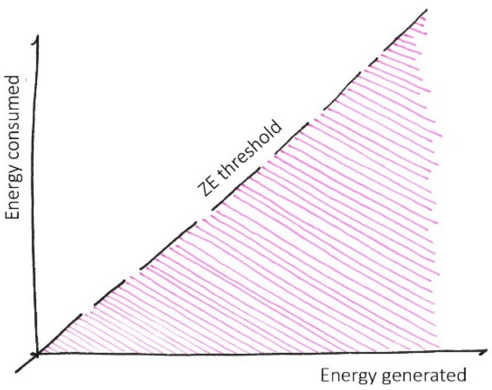


Figure 5. Graph representing the zero energy threshold (by the Author based on Sartori et al., 2012:222—Fig. 2).

The energy standards are set to their own thresholds and energy connotations. The most common for ZEBs is that the energy produced on-site is negative and that all the energy from the grid is positive, even though some of the primary energy[6] is produced via carbon-free methods. Calculating the amount of prime energy coming from carbon-free sources is impractical because most energy comes from carbon sources, energy grids are unstable and carbon-free energy is untraceable (Williams, 2012:25-27,32).

For example, PlusEnergy buildings or Energy-plus-houses is a zero energy standard where negative and positive connotations are inverted but the threshold balance remains

6 Primary energy refers to the energy produced in power plants, as the source of the energy grids.

the same (Voss & Musall, 2013:28-30). The Passive House standard also set thresholds of energy consumption, but these are fixed and unaffected by the amount of renewable energy produced by the building.

(2) Grid connection

The measurement of the energy balance is determined by the connection of the building to the grid and the location of the primary sources. Buildings can be, or not, connected to energy grids. The zero energy balance of connected buildings depends on their interaction with the grid. The balance of the connected buildings is known as 'net zero energy' (Hernandez & Kenny, 2010:817; Sartori et al., 2012:1; Marszal & Heiselberg, 2009:6).

Energy grids may be double way, delivering energy to a building and receiving energy back from it (Sartori et al., 2012:221). Thus, the most common approach to a net-zero energy balance is by using the electricity grid as a source and sink, avoiding the storage of energy on-site. The energy balance can be determined by comparing different energy flows.

Buildings not connected to the electricity grid are usually known as 'off-grid'. The off-grid building needs to offset all their electric consumption through their mediums, being this usually carbon-free (Laustsen, 2008:71; Lund et al., 2011:1646).

Off-grid buildings need to use an electricity storage system (batteries) for periods with peak loads. Thus, they are criticised for the environmental consequences that storing energy produce and the requirement of proper disposal management (Marszal et al., 2011:974-975; Hernandez & Kenny, 2010:817). Their other energy reserves, like water or gas, might require being filled from external sources. Thus, off-grid buildings energy balance is simple to predict as their production and storage capacity restrains them, however, does not mandatory mean a zero energy balance.

(3) Metric (balancing indicators)

The ‘metric’ refers to the way energy is measured. It refers to the units used to measure energy content, as well as to the parameters set to establish the boundaries of the energy system (Voss & Musall, 2013:31).

The energy units are those defined denominations used to quantify energy transfer. Examples of these units are the ‘Joule’ (J), ‘Calorie’ (cal), ‘British thermal unit’ (Btu) or ‘Watt’ (W). These units can be converted to their equivalents to relate them with other units of measurement. The kilowatt-hour (kWh) is the standard unit of electricity production and consumption[7].

Watt, and hence kilowatt-hour, are units that quantify the amount of energy that flows during a specific time. Thus, these units are practical to measure energy balances in the built environment.

The parameters that establish the form and boundaries of an energy system are those that define the energy chain, including the properties of natural energy sources, conversion processes, transmission and distribution grids (Sartori et al., 2012:224). Different from

[7] ‘kWh’ is the energy unit that measures the amount of energy of appliances. kW refers to 1,000 watt; therefore, 1 kWh refers to an appliance of 1,000 watts running for 1 hour. Accordingly, 1 W is equal to 1 J per second.

the measurement units, the zero energy balance depends on the selection of the parameters.

The concept of 'zero energy' sometimes gets appropriated by social, cultural, political or contextual ambitions. Setting different parameters would relate the energy balance to different stands (Marszal et al., 2011: 2). Governments and other entities in charge of regulating (or certifying) energy consumption in buildings have different definitions of the energy balance determined by the measurement units and parameters they choose (Berry et al., 2014:307; Voss & Musall, 2013:40-46; Williams, 2012:20)[8].

The energy consumed by buildings connected to grids is produced in an energy plant and transmitted to the building. The transportation or transmission process implies a loss of energy, which also needs to be calculated to relate to CO_2 emissions. Net-zero energy calculations require to consider the appropriate 'weighting factors' based on a series of numerical assumptions (Passivhaus Trust, 2019:4).

The weighting factors refer to those systems used to convert the physical units of different energy carriers into uniform metrics, hence allowing the evaluation of the entire energy chain. It includes the properties of natural energy sources, conversion processes, transmission and distribution grids (Sartori et al., 2012:224).

The location of the energy source and transmission distances are factors likely to change during the building lifetime. Considering primary energy or CO_2 emissions for the energy

[8] Voss & Musall (2013:40-46) categorise different definitions from geographical context, while Williams (2012:20) arrange them by parameters.

balance, as zero Carbon, have impractical implications. Thus, watts, or more specifically, kWh, are more convenient metric unit used to measure energy consumption and production (Berry et al., 2014:308).

(4) Balancing period

The 'balancing period' refers to the period over which the energy balance is calculated or measured (Marszal et al., 2011:972). The balancing period is set to match periods of the established time. The balance calculations adjust to the established time spans, rather than adjusting these to the moments of equilibrium. The balancing periods usually follow time span conventions, like a day, month or year.

Daily periods are useful to represent the balance between day and night energy production and consumption; however, these overlooks differential seasonal conditions. Monthly periods calculations present similar bias. Annual spans are useful to calculate operational energy performance concerning climate cycles because they provide a better average (Sartori et al., 2012:225; Voss & Musall, 2013:34; Berry et al., 2014:308; Hernandez & Kenny, 2010:817; Lund et al., 2011:1647; Stene et al., 2018:10-11).

Embodied energy calculations set the balancing period to the full life cycle of the buildings (Voss & Musall, 2013:29). 'Life-cycle assessments' (LCA) are used to analyse the environmental performance of buildings. LEED in the USA, BREEAM in the UK and EcoEffect in Sweden are examples of LCAs used in practice (Cabeza et al., 2014:395,399). Lifespan balancing periods confront issues related to precision, mainly because its calculation is based on future scenarios (Berry et al., 2014:309).

(5) Balance type

The ‘balance type’ refers to the criteria used to verify the balance of energies; in other words, a comparison of energy consumption against energy production (Berry et al., 2014:309). There are three different balance types, which are determined by the location of the building boundary, energy generators and energy consumers.

- *Generation/load*—balance defined by the energy consumption load of the dwelling’s appliances, against the energy production of renewables in the site (Marszal el al., 2011:974). The generation/load balance type is a direct sum of the energy consumed against energy produced by the building. The following diagram shows an example of a generation/load balance (Fig. 6).

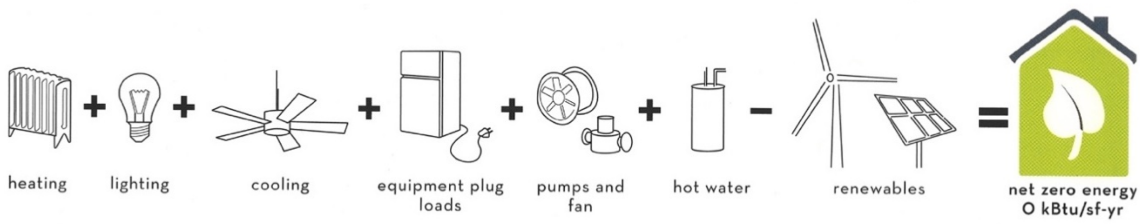
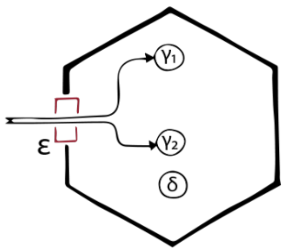


Figure 6. Concept of generation/load energy balance of a ‘net zero’ building (Source: Maclay, 2014:18— Figure 2.1). Notes: energy buildings load matched by renewable energy production on an annual basis. The diagram proposed by Maclay is a theoretical example; thus, it overlooks some energies as the heat produced by internal occupants.

The generation/load balance type has practical implications, particularly for the purchasing decision-making process of appliances and renewables. However, it overlooks all weighting factors, resulting in unprecise calculations (Sartori et al., 2012:226).

- *Input/output*— this balance type is defined by the energy flows that happen through electric conduits measured at the identified dwelling boundary. The energy flowing into the dwelling is positive, while the one flowing out is negative. The positive connotation is given assuming that the energy generated in the house is produced through renewables, while the negative energy has been extracted from the electric grid, which source is unknown.

The following diagram exemplifies the input/output balance type in reference to the zero energy balance diagrams. In this case, the system refers to the building, and the energy can only flow in and out through a defined boundary (ε), usually a meter. Appliances and mechanical systems (γ_1 & γ_2) consume energy, while renewables (δ) produce energy (Figs. 7 & 8).



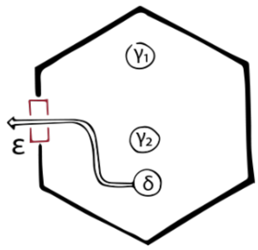


Figure 7. Energy system where (positive) energy is consumed. Figure 8. Energy system where (negative) energy is produced through renewables (diagrams by the Author).

This balance type considers that the weighting factors only inside the dwelling boundary, which accounts for internal transmissions or inefficiency of appliances. The input/output balance has practical implications in verification on built projects as it can be measured using energy meters.

- *Exported/imported*— this balance type is calculated by comparing the energy surplus of the energy produced by renewables minus the energy produced by the energy source including energy lost in transmission (Fig. 9).

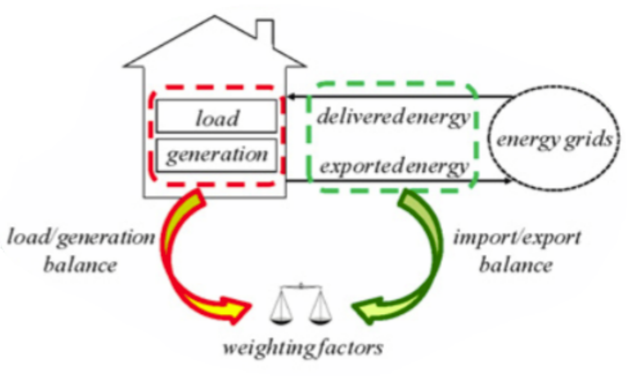


Figure 9. Import/export balance between weighted exported and delivered energy (from Sartori et al., 2012:226— Fig. 3).

The exported/imported balance provides useful information concerning primary energy. However, it requires estimates of self-consumption patterns and detailed simulation of uncertain factors (Sartori et al., 2012:226; Berry et al., 2014:309).

(6) Energy usage coverage

The 'energy usage coverage' refers to the type of energy contemplated in zero energy calculations. It is considered to its physical characteristics, like electric energy, gas, heat, wind or solar power. Energy usage coverage extends to the generation, transformation, transportation and consumption of electricity set by the building boundary.

Electrical energy and gas are the types of energy most commonly used in the housing practice; most energy standards only contemplate these. The housing market benefits of avoiding prime energy calculations as these tend to be imprecise and hard to verify by the customer (Berry et al., 2014:310).

(7) Generation type

The ‘generation type’ refers to the ways of generating electric energy. These could be from processes that produce CO_2 emissions, or those that are carbon-free— also known as renewables (Berry et al., 2014:311).

Renewables are those types of energies obtained from natural sources that do not deplete finite resources, and its processing does not produce CO_2 emissions (Maclay, 2014:1; Marszal et al., 2011:974). As stated before, the positive or negative connotation is related to the generation type.

The categorisation of energy generation types depends on contextual interpretations. For example, in the UK, renewable energy sources are hydro, wind, solar photovoltaics and active solar heating, deep geothermal and heat pumps, and bioenergy. Bioenergy process does release CO_2 emissions but is considered renewable because it comes from organic material, which sequestrates CO_2 during its lifetime. Nuclear energy, which does not release CO_2 emissions, is not considered a renewable source because of it produce waste that impact the environment (Department for Business, Energy & Industrial Strategy, 2018:27,31; Committee on Climate Change, 2018:38-40). Only a few processes are commonly commercialised in the domestic scale, like wind, solar and, in some scenarios, heat pumps.

(8) Spatial boundary and generation location

In terms of energy transmission, the point where the building interacts with the electric grid delimits the boundary of the dwelling/site, which is set by the location of the energy meter and goes following contextual legislation. Naturally, the spatial boundary concept only applies to the quantification of operational energy, as embodied energy is not limited to the on-site energy consumptions (Berry et al., 2014:313).

The spatial boundary of an energy system might not be the same as the property. The spatial boundary is where the dwellings' meters locate. Buildings that us a central district energy system share a single spatial boundary (Williams, 2012:119-155).

The 'generation location' refers to the classification of a building depending on the location of the renewable appliances in accordance with the building. There are three different arrangements for the location of the energy generators (Maclay, 2014:23,27) (Fig. 10)

- *Net zero project*— renewables located at a remote location (out of the site boundary), but the energy produced is attributed to the site.
- *Net zero site*— renewables are contained inside the building site, but independent from the dwelling structure.
- *Net zero footprint*— renewables are an integral component of the dwelling structure.

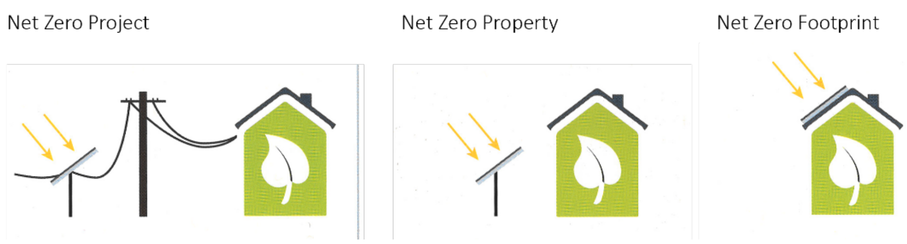


Figure 10. Classification of net zero buildings in three categories depending on the location of the renewables (modified by the Author from Maclay 2014:27— Figure 2.8).

The generation location affects the zero energy balance calculation. The net zero project implies energy generation outside of the dwelling boundary and usually refers to district energy (Hootman, 2013:266-267). For net zero project buildings, the energy balance is not measured by living unit, which means that some dwellings might not achieve zero energy (Hartley, 2018).

The generation of energy in net zero property and net zero footprint dwellings is contained inside the dwellings´ boundaries, which allow input/output balance type calculations. Spatial boundaries and generation location set to single dwellings are more compatible with the housing practice and the calculation of ZEB.

Zero energy building definitions

The following definitions are the more consistent references to 'zero energy buildings' in literature and most generally accepted in practice (Torcellini et al., 2006:4-5, 11; Sartori et al, 2012:10; Voos & Musall, 2013:15; Aelenei et al., 2016:277,293; Marszal et al., 2011:972; Maclay, 2014:23,26,27; Hootman, 2013:5-10).

- *Net Zero Site Energy*— the building produces at least as much energy as it uses when audited at the grid interaction at the boundary of the building site giving a net value of import energy of either zero or less than zero.

- *Net Zero Source Energy*— the building produces at least as much energy as it uses in a year when accounted by the primary energy used to generate and deliver the energy to the site and set against that generated on-site. The measurement point is set to the site boundary; therefore, the energy values are scaled to account the weighting factors to account primary or source energy.

- *Net Zero Energy Emissions*— the building that produces at least as much renewable energy as it uses from emissions-producing energy sources. Contemplate renewable energy from primary sources in the balance. The balance refers to emission factors and not on electric energy.

- *Net Zero Energy Costs*— the energy charges for the operational use of a building are equal or less than the amount of money the utility pays the owner for renewable energy the building feeds into the grid. Currency is used as a metric to measure energy flows. The boundary and calculations are mandatory related to the position of an electric meter.

These definitions were originally introduced by Torcellini et al. (2006:1,4-5) to set a unified approach and development of certificates. These definitions attempt to compress all the possible combinations of metrics and boundaries. However, the factors used to determine them are different, inequitable and, for some, not comparable (Hootman, 2013:10). Consequently, the particularities of each definition make them only appropriate for some contexts. The following table presents a critique of these definitions concerning the housing practice and the ZEMCH concept (Table 6).

Table 6. Net-zero energy definitions and its compatibility to the housing practice and ZEMCH concept.

Definition	*Compatibility with housing practice and ZEMCH concept*	*Incompatibility with housing practice and ZEMCH concept*
Net Zero Site Energy	- Verifiable on-site - Not affected by external factors - Easy to understand by end-user (house buyer)	- Does not account primary energy, and thus, imprecise CO2 emissions

	- Energy calculations are site-free, allowing housebuilders to compromise to achieve zero energy in multiple sites	
Net Zero Source Energy	- Able to equate energy value of fuel types - Capable of measuring impact on the national energy system - Account primary energy, which relates to CO2 emissions	- Energy information confusing, imprecise and unverifiable for end-users. Technical calculations required contemplating transportation weighting factors - It does not allow prototyping assumptions as calculations need to be specific to each site conditions
Net Zero Energy Emissions	- Balance that represents precise carbon neutrality as calculations made direct on CO2 emissions	- Energy information confusing, imprecise and unverifiable for end-users. Technical calculations required contemplating transportation and conversion weighting factors - It is measured in CO2 metrics, not in energy - It does not allow prototyping assumptions as calculations need to be specific to each site conditions
Net Zero Energy Costs	- Easy to understand, verify and measure by end-users - Encourages energy efficiency from the user end as it has an economic impact on their lifestyle	- It might not reflect an energy or carbon balance as energy can be sold and purchased at different rates - It might not be applicable in specific contexts - Volatile over time - Billing periods might not match annual calculations

The comparison of different zero energy buildings require comparable parameters, otherwise, it is like *'like comparing apples to pears'*. Pan (2014:427-434) proposes a system of boundaries where factors determining the zero energy definitions are accounted and therefore different types of zero energy buildings compared to each other. Accordingly, it is meaningless pointing a definition as being *better* than the others, each is selected in relation to its context and in the interests of the designers, constructors, certification agencies or governmental entities.

The theoretical relationship between zero energy and mass customisation cannot be positioned to any of the categories set by Torcellini or Pan. ZEMCH, as a principle, needs to remain neutral unattached to any political, geographical, policy timeframes and institutional parameters.

Relating zero energy to mass customisation requires the selection of a single definition (Berry et al., 2014:315-317; Maclay 2014:26). This research selects Berry et al.

(2014:317) definition because the factors selected are highly compatible with the housing practice and the principles of the ZEMCH concept. Their definition of zero energy building is quoted as,

> *'A net zero building is an energy efficient building that generates sufficient energy on-site over the course of a year to supply all expected on-site energy services for the building users.'*

This definition is consistent with Torcellini et al.´ 'net zero energy site' definition, with the slight differentiation that includes the term 'energy-efficiency' as a prefix to the building. Thus, it implies that achieving energy balance is not enough to achieve zero energy characteristics[9].

Mathematically speaking, efficiency is unrelated to the balance. An inefficient energy house that consumes high amounts of energy could achieve the zero energy balance by producing an equally high amount of energy. However, carbon emissions are still released to the atmosphere despite the generation of renewable energy, which does not correspond with the environmental principles of zero energy (Nieboer et al., 2012:1). Accordingly, other energy standards, as Passive House, focuses on energy efficiency rather than on energy balance.

For the built environment, energy efficiency commonly refers to those buildings designed to provide a significant reduction of the energy needed to operate (Patterson, 1996:377,386-387; Greening et al., 2000:398).

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9 Paul Torcellini, author of 'Zero Energy Buildings: A Critical Look at the Definition', develop in collaboration with other expertise a governmental document entitled 'A Common Definition for Zero Energy Buildings' in 2015. In it, a 'Zero Energy Building' is defined as *'An **energy-efficient** building where, on a source energy basis, the actual annual delivered energy is less than equal to the on-site exported energy.'*(Peterson et al., 2015:4). Despite referring to *energy source*, the term 'energy-efficiency is also included as part of the new definition.

Voss & Musall (2013:16) declare that *'zero energy buildings are primarily energy-efficient buildings… [because] without a consistent efficiency strategy, a path towards net zero energy buildings isn't available!'*. Voss & Musall mean that energy-efficient design strategies are needed for the conception of ZEB because on-site renewable technology is not capable of supporting high consumption levels. The following table presents the factors selected by this research to define zero energy. (Table 7).

Table 7. Net-zero energy definition and determining factors compatible with the housing practice and mass customisation.

A zero energy dwelling is an energy-efficient dwelling that generates enough energy on-site over a year to supply all expected on-site energy services for the dwelling users.		
factors	*definition*	*factor compatible with housing practice and mass customisation*
Energy balance	A dwelling that produces as much energy as it consumes	Energy efficiency
Grid connection	Status of the building in relation to connections to grids	Net-zero energy dwelling
Metric	The way energy is measured	Energy quantifiers, as for electricity and gas is KWh— kilowatt-hour
Balancing period	The time over which the energy balance is measured	Annual
Balance type	The criteria used to verify the balance of energies	Input/output balance
Energy usage coverage	The type of energy contemplated in zero energy calculations	On-site generation, operational energy up to energy meters
Generation type	The different ways of generating electric energy	Renewable energy on-site concerning local definitions. UK case wind, sun and biomass
Spatial boundary	The point where the building interacts with the electric grid	Location of the electric meter
Generation location	The classification of a building depending on the location of the renewable appliances in accordance with the building	Net-zero footprint

This definition implies that a connection to electrical grids; thus, it really refers to 'net' energy. However, this research does not mention the word 'net' to avoid redundancy and to semantically relate these to the ZEMCH concept (Hernandez & Kenny, 2010:817; Sartori et al., 2012:1; Marszal & Heiselberg, 2009:6).

Defining 'Mass Customisation'

'Mass Customisation' refers, in its basic terms and from a production perspective, to the ability to provide customised products, or services, for individuals at scales, costs or efficiencies that resembles 'mass production' (Hart, 1995:36; Gilmore & Pine, 1997:91; Sandrin, 2014:159; Da Silveira et al., 2001:1; Fogliatto et al., 2012:15; Rudberg & Wikner, 2004:446). However, mass customisation does not have a generally agreed definition. It is a complex and even confusing term (Piller, 2004:314; Zipkin, 2001:81; Bardakci & Whitelock, 2003:464-465; Duray, 2002:314-315).

Theoretical background

'Mass customisation' emerged as a theoretical business proposal. The term was coined in 1987 by Stanley Davis, who was inspired by Alvin Toffler's vision for diversity through technology (Da Silveira et al., 2001:2; Hart, 1995:45; Piller & Steiner, 2012:6; Piroozfar & Piller 2013:4; Noguchi, 2012:iii; Noguchi, 2013a:5; Tseng & Jiao, 2001:685). Davis (1987:166), in his book 'Future Perfect', states the following.

> *'Alvin Toffler believes that the computerized assembly line can bring customized products within the reach of the average person; ... and for* ***houses*** *and cars, as well as clothing, hamburgers, and birthday cards.'*

Davis refers to Toffler three times in his book (Davis, 1987:13,106,166,169). It is possible to grasp the influence of Toffler in Davis' texts, not only from how similar the books were entitled— 'Future Shock'[10] of Toffler in 1970 and 'Future Perfect' of Davis in

10 Alvin Toffler (1970:4) defines the Future Shock as a psychological state of individuals and society to perceive and deal with "too much change in too short time". He came with this concept five years before writing his book to describe the shattering and disorientation that people induce with changes.

1987— but on how they describe the need for variability (customisation) in production processes as a consequence of the segmentation of markets. Toffler (1980:11) described this phenomenon as follows.

> *'… managers were taught that mass production is the most advanced and efficient form of production… that a mass market wants standardized goods… that mass distribution is essential… that "masses" of uniform workers are basically all alike and can be motivated by uniform incentives. ... Today, ... the corporate manager finds all his old assumptions challenged. The mass society itself... is becoming* ***demassify****. ... The mass market has split into ever-multiplying, ever-changing sets of minimarkets that demand a continually expanding range of options, models, types, sizes, colors, and* ***customizations.****'*

Here, Toffler is referring to the need to invert production processes, where customers decide what they want to be produced rather than manufacturers deciding what to make. In other words, where production is *pulled* by the market rather than *pushed* to the market (Agrawal et al., 2001:65-66; Cuperus, 2003:10; Toffler, 1970:3; Noguchi et al., 2016a:96). Toffler (1970:236) describes the need for variability with the following example related to housing.

> *'"There are ten times the new styles and colors there were a decade ago," says John A. Saunders, president of General Fireproofing Company, a major manufacturer in the field. "Every architect* ***wants*** *his own shade of green."'*

Certainly, housing designers have different preferences. However, customisation comes from the need to provide end-user with what they want and need. Samuel Gonçalves (personal information, June 2019), designer of prefabricated houses, explains how the need for customisation comes from the client and not from the designer.

> *'...if it was for me, I would repeat always the same project, but that would never happen, it's impossible. When people think about architecture, they think about customisation. Architecture is an activity of customisation.'*

Davis (1987:169), for its part, describes the current need for variability as a natural evolution of the marketplace, using the term 'mass customisation' to define the current situation (Fig. 11).

> *'Mass customization of markets means that the same large number of customers can be reached as in the mass markets of the industrial economy, and simultaneously they can be treated individually as in the customized markets of pre-industrial economies.'*

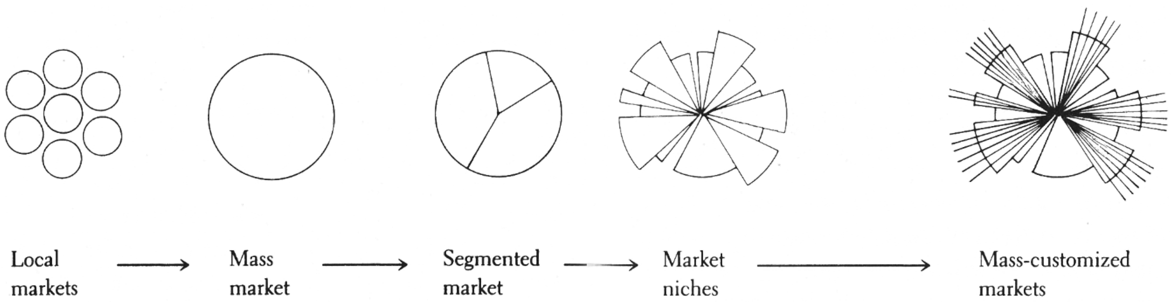


Figure 11. Market development (from Davis, 1987:169— Figure 3).

Toffler believed that existing manufacturing systems were able to produce variable products at mass production costs (Noguchi et al., 2016a:96). Following Toffler's ideas, Davis proposes the merge of customised and mass production processes to cope with diversity. Davis (1987:140) explains this apparently contradictory situation as follows.

> *'The world of mass customizing is a world of paradox with very practical implications. Whether we are dealing with a product, a service, a market, or an organization, each is understood to be both part (customized) and whole (mass) simultaneously.'*

This paradoxical situation where customisation (bespoke) and mass production systems merge into a single concept is the most constant argument used in the theoretical construction of mass customisation (Duray et al., 2000:605-606,617; Noguchi, 2013a:5). As David Hounshell (1984:263) states in his book 'From the American system to mass production', '*Paradox is part of the stuff of history.'*

B. Joseph Pine II popularised the mass customisation concept in 1993 with the publication of his book that was concretively entitled 'Mass Customisation'. Pine also defines mass customisation as the merge between mass production and customisation (Noguchi, 2013a:5). Pine's (1993:xiii,44) texts focus on understanding what mass customisation means as a business and marketing concept, describing it as follows.

> *'While practitioners of Mass Production share the common goal of developing, producing, marketing, and delivering goods and services at prices low enough that nearly everyone can afford them, practitioners of Mass Customization share the goal of developing, producing, marketing, and delivering affordable goods and services with enough variety and customization* ***that nearly everyone finds exactly what they want****.'*
>
> *'[Mass customisation] At its core is a tremendous increase in variety and customization without a corresponding increase in costs. At its limit, it is the mass production of individually customised goods and services. At its best, it provides strategic advantage and economic value.'*

Pine (1993:xiii) refers to mass customisation as *'the new frontier in business competition'*. Pine, as Davis and Toffler, describes mass customisation as an evolutionary process determined by social and economic changes, where mass production, was a sophistication of pre-industrial models (James & Mondal, 2019:638; Toffler 1980:283-285).

Hence, mass customisation is a concept that originated from a business perspective. In terms of housing, Walter Gropius, John Habraken and Le Corbusier envisioned the possibility of producing customisable houses through industrialised processes. In recent years, mass customisation has emerged as a potential solution for delivering variability using manufacturing building processes (Gropius, 1956:146; Habraken, 1972:40-58; Le Corbusier, 1974:210-217; Herbert, 1984:5; Aitchison & Macarthur, 2017:81-84). For example, Kieran & Timberlake (2004:xii-xiii), who also recognise mass customisation as the synthesis[11] of mass production and customisation, describe the reasons for believing that mass customisation is a feasible and beneficial way of producing houses as follows.

> *'What has changed today? Everything. Mass production was the idea of the early twentieth century. Mass customisation is the recently emerged reality of the twenty-first century. We have always customized architecture to recognize differences. Customization ran at cross purpose to the twentieth-century model of mass production. Mass customization is a hybrid, but with the ability to differentiate each artefact from those that are fabricated before and after. The ability to differentiate, to distinguish architecture based upon site, use, and desire, is a prerequisite to success that has eluded our predecessors. With the information control tools we now have we are able to visualize and manage off-site fabrication of mass customized architecture. Architecture has over the past century finally become a machine, with as much as fifty percent of cost embedded in systems, not structure, walls, and roof. Developments of lightweight, high-strength, and high-performance materials offer the prospect of economy, efficient*

[11] Referring to the way Karl Marx and Friedrich Engels define 'synthesis' in their study of contradictions — 'Dialectics' — which is recognised as a method to merge contraries as a process of development rather than a process of conflict, where the best aspects of each concept are merged into one.

> *transport, re-use, and less waste all of which streamline the process cycle. Architects constructors, and clients reap the rewards.'*

Mass production vs customisation

'Mass production' refers to the '*single-purpose manufacture combined with the smooth flow of materials; the assembly line; large-volume production; high wages initiated by the five-dollar day; and low prices'* (Hounshell, 1984:263). In other words, mass production refers to the manufacture of large quantities of standardised products (Noguchi et al., 2016a:102).

In contrast, 'customisation', or also referred to as custom production, refers to the production of bespoke objects through crafted processes. From a production system perspective, custom production refers to the production system where economic production was all crafted by the hands of someone who had the necessary materials, tools and skills to turn raw materials into finished goods (Pine, 1993:9).

Up to a certain point in history, crafting was the only production mean. Mass production resulted from the industrial revolution, which brought a general replacement of tools with machinery and human/animal power with fossil fuels (Pine, 1993:9; Toffler, 1980:41). Accordingly, mass production is considered an evolution, or sophistication, of craft the ancient crafting system (Pine, 1993:9-50; Davis, 1987:161-162; Toffler, 1980:55-61,283; Fralix, 2001:3).

Mass production is based on the standardisation of the production process. Homogenous production lines make the production process more effective, in time, cost and scale

(Noguchi et al., 2016a:98). Henry Ford described mass production as *'...the focusing upon manufacturing project of the principle of power, accuracy, economy, system continuity, and speed'* (Hounshell, 1984:217).

mass production is characterised by the use of a linear manufacturing system, also known as 'production-line' organisation. The production-line organisation refers to the production arrangement where the flow of material is fully determined and organised by a transport system or conveyor line. The workstations are synchronised and there are no buffers in between (Bock & Linner, 2015:137). The following image illustrates the production-line organisation manufacturing system (Fig. 12).

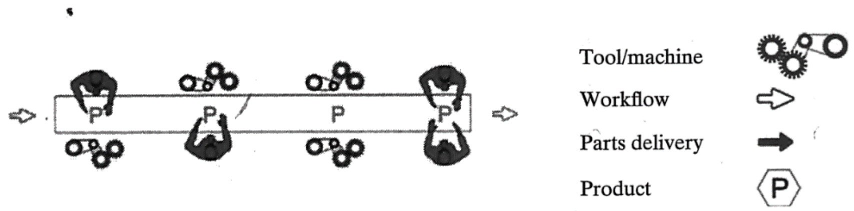


Figure 12. Production-line manufacturing organisation present in mass production processes (From Bock & Linner, 2015:137).

The production of the 'Ford T' car is a clear example to describe the production benefits of mass production and its production process. The Ford T production centred on the industrialised production of interchangeable parts with specialised machines focusing on the process of production and division of labour. The Ford T production followed a hierarchically managed rigid assembly line where specialised workforces focus on unique tasks. Thus, production was highly controlled, and all products standardised. As a result, the production operation efficiency increased while costs decline (Pine, 1993:15; Hounshell, 1984:217-261). In less than ten years, the retail cost of a Ford T reduced by half, and production increased over 9000% (Noguchi et al., 2016a:98; Clymer, 1955:134-137). The following images present a section of the Ford T assembly line and the economic benefits in terms, of the retail price and production scale (Figs. 13 & 14).

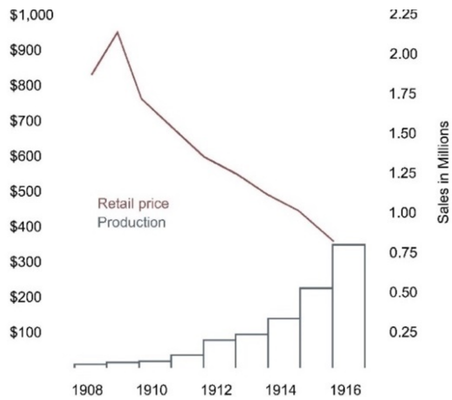


Figure 13. Ford T assembly line at ‘Highland Park’ in 1914 (Source: Hounshell, 1984:257—Figure 6.32). Figure 14. (right) Ford T retail price in comparison to production from 1908 to 1916 (Sources: Pine, 1993:17; Hounshell, 1984:224; Clymer, 1955:134-137)

However, craft production was not entirely replaced with the rise of mass production systems. Today, both systems coexist because their offer to society is different. In custom production, craftsmen offer a service rather than a product. Customers approach the craftsmen directly and explain precisely what they want; then, the craftsmen will elaborate a custom production process based on the customer’s wants, needs and measurements (Fralix, 2001:3). In other words, it is the production process, which is customised, and the uniqueness of the product is a direct consequence of it.

The most common manufacturing arrangement present in craft production is the ‘workbench-like’ organisation, which refers when the product remains at a fixed station through the whole production and the production processes change depending on the stage of the production process. Times and sequences are not standardised or synchronised with other stations; thus, each production can be different (Bock & Linner, 2015:137). The following image illustrates the workbench-like manufacturing organisation usually present in craft and custom productions (Fig. 15).

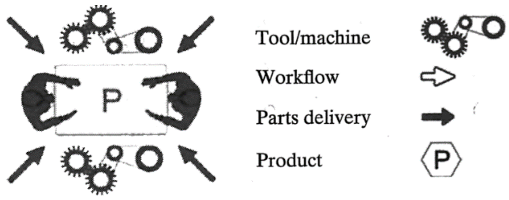


Figure 15. Workbench-like manufacturing organisation (From Bock & Linner, 2015:137).

In custom production, there is no marketplace. The market, as the exchange network or switchboard were goods and service are routed to their appropriate destinations, was a consequence of the introduction of mass production, where production and consumption split from each other and products need to be displayed to the consumers (Toffler, 1980:55,58). The following image illustrates the consumption process present in mass production markets. (Fig. 16)

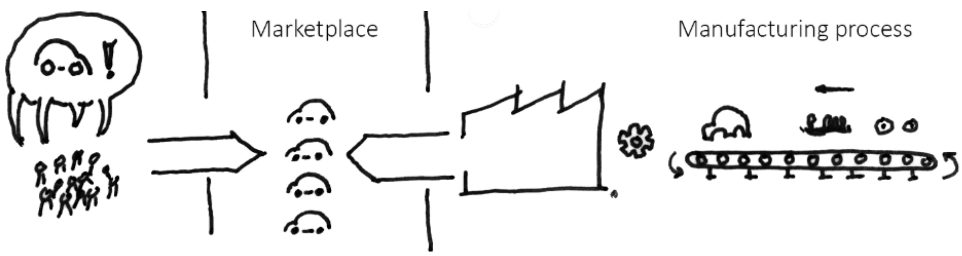


Figure 16. Mass production purchasing and production processes (Diagram by the author).

For custom production, the purchasing and production of custom goods are a single process; where the customer and craftsmen have direct interaction, and production only happens after this meeting (Fig. 17).

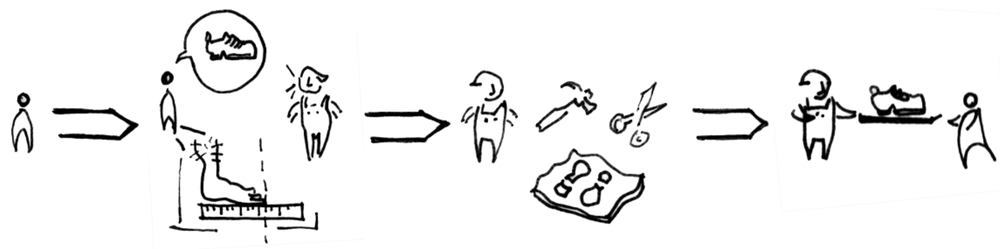


Figure 17. Custom product purchasing and production process (Diagram by the author).

Both systems have clear advantages and limitations. On the one hand, mass production is cost and time-effective, but have rigid supply chains incapable of producing different products. On the other hand, custom production is bespoken to the exact wants and needs of the customer uncertain about production capacity and pricey compared to mass-produced products (Duray et al., 2000:611; Fralix, 2001:3). The apparent high costs, and refined uniqueness, of crafted products, are a result of the cost-cuts and homogeneity of mass production (Barlow, 1999:29).

In mass production economies, customers satisfy their particular wants and needs by comparing and choosing from the different products offered in the marketplace. Mass producers distinguish from each other by specialising to the wants and needs of a particular market niche. However, as these niches keep on diversifying, mass producers struggle to adapt to heterogeneity (Davis, 1987:161; Kotha, 1996:442-443; Fralix, 2001:3). The following images describe the current market situation, where the market diversified due to the competition of diverse manufacturers, each with their mass production process, but still, struggle to cope with increasing diversity (Figs. 18 & 19).

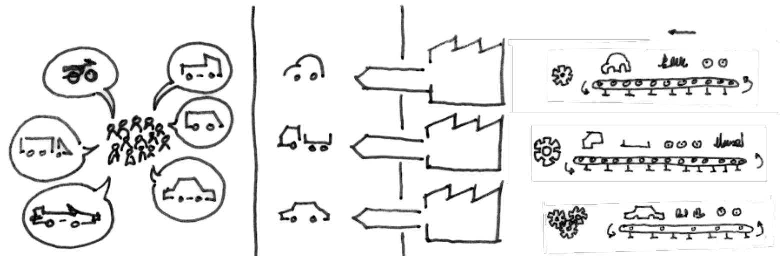



Figure 18. (left) Market niches in a segmented market (fragment from Davis, 1987:169) Figure 19. (right) Mass production struggles to supply segmented markets (Diagram by the author).

The mass production processes are efficient if they are stable because they use assembly lines that work with specialised machines and labour routines to produce homogenous products (Pine, 1993:15). If they want to vary their production, they require to modify their production processes, which runs against the principles of mass production and require substantial investments.

There are examples of mass production manufacturers who bankrupted because they were incapable of coping with emerging social wants and needs. For example, ‘Kodak’, manufacturer of photographic cameras and film, bankrupt in 2012, provoked by the increasing demand for digital photography (Djudjic, 2018; Viki, 2017). The ‘DMC DeLorean’ automobile company fail as it did not manage to recover from its initial investment. The sales of their only car model were lower than expected, due they were targeting a particular market niche, adding that their sales were affected by the bad reputation attached to the director’s personal life (Prisco, 2019; Chung, 2016) (Figs. 20 & 21).

Figure 20. (left) DeLorean single-car exhibit in the USA (Source: Chung, 2016). Figure 21. (right) DeLorean Motor Company factory in Belfast, Northern Island (Source: Chung, 2016)

In terms of housing, there are also historical examples of production ventures that fail due to the inflexibilities of mass production. A clear example is the 'Lustron Houses' produced in the USA from 1946 to 1950. The Lustron houses were prefabricated bungalows assembled on site, where all components were entirely produced on factory through long production lines by a single company. The Lustron project was funded by the government and local investors and managed to produce 2,500. However, the company bankrupted after only four years of being founded and with an active time of two years (Waite, 2012; Buck, 2017). Many factors are attached to the Lustron's failure, but mainly that they were unable to accommodate the variability demanded (Davies, 2005:57-58; Wolfe & Garfield, 1989:58; Herbert, 1984:313-325; Aitchison & Macarthur, 2017:86-88). The Lustron House and other examples of failing ventures to industrially produce houses are described in chapter 6. The following images show the appearance of the Lustron Houses (Figs. 22 & 23).

Figure 22. (left) Lustron Corporation president in front of a Lustron house in 1949. Figure 23. (right) Standing Lustron House in Chesterton, Indiana (Source: Buck, 2017).

The housing market demands higher levels of personalisation than other markets. Houses different to cars and other products are fixed to a site and its climatic conditions (Gropius, 1956:146; Habraken, Pawley, 1971:96-970; Kendall, 2013:43). Graham Shawross, who worked for the UK Ministry of Works, in the design of prefabricated houses for the council, stresses the need for variety as follows.

> *'Variety comes from what people do, from the decisions they make. Customisation should come from individual choices. And then it's real, anything else is artificial variety, always looks very unsatisfactory.'*

Variability and upgrading of production lines require investment. Mass production principles of reduction of production costs do not represent an advantage in segmenting markets. Recalling the Ford T example, its production only lasted from 1908 to 1927; and during this time, they were forced to introduce variations and improvements to compete in the rising automobile market (Alizon & Shooter, 2009:597-602; Clymer, 1955:134-136). Consequently, the Ford T production turned unstable and production costs suffer fluctuations. The following graphic shows the retail price and production volume of the whole production of Ford T cars (Fig. 24).

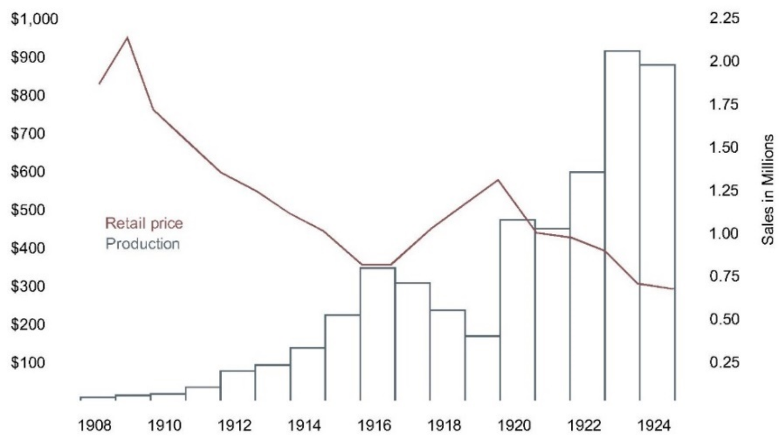


Figure 24. Ford T retail price in comparison to production from 1908 to 1924 (Sources: Pine, 1993:17; Hounshell, 1984:224; Clymer, 1955:134-137)

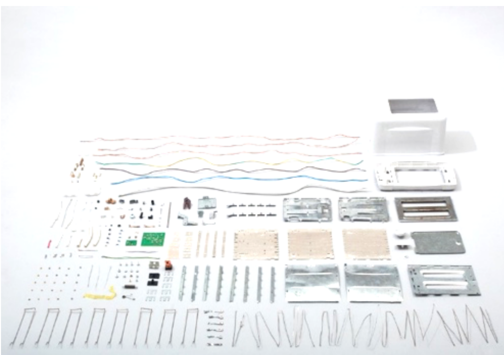
Customisation and personalisation are, indeed, social desires; however, variability and industrialised customisation are production needs. Manufacturers require to adjust to consumption patterns to keep their production finances stable and healthy. Thus, the need for customisable production comes from an industrialised production stand.

Dependency on industrialisation and mass production

It is suggested that the production of houses different than cars or other products, is not dependant to industrialised mass production. This is true only to the extent that houses can be built outside a factory. However, there are inevitably components and tools used in construction that are dependant to industrialisation and mass production, from a screw to a door handle.

The housing dependency on industrial mass production intensifies when the house is expected to generate energy from renewables, which is an essential component of zero energy houses. Photovoltaics, wind turbines, efficient heating/cooling systems, hermetic double/triple glazing windows, insulation panels, and any mechanical system are components produced through industrialised processes. All these are dependant to industrialisation, not only from an engineering or technological perspective but in production cost and quality (Etherington, 2012).

‘The Toaster Project’ by Thomas Thwaites is an example of the social dependency on industrialised processes. In it, Thwaites demonstrated that crafting a simple electric appliance (toaster) from scratch— meaning extract of raw material, conversion into parts and components, and assembling— was more costly and less efficient than the ones offered in the market. The production of his toaster cost £1187.54 in comparison to £3.94 of a generic one. The time Thwaites expended in the production of the toaster was of nine months, which might take a few hours for a manufacturer. Thwaites also acknowledges that his toaster was not performing as the mass production one; actually, it was deficient, dangerous and self-destructive (Thwaites, 2011:13-15) (Figs. 25 & 26).



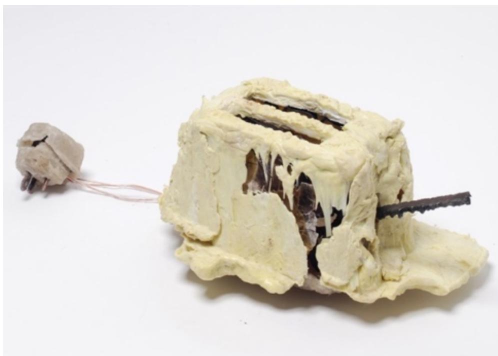


Figure 25. Components of a generic mass production toaster (Source: Thwaites, 2011:16-17). Figure 26. Thomas Thwaites toaster (Source: Etherington, 2102).

The dependency of housing to industrialisation relies on the production of construction components; which for zero energy housing, is on the certainty of performance, meaning how much energy will consume and how much will generate.

Synthesis of mass production and customisation

Mass Customisation is an ideal production system that takes the strengths and avoids the weaknesses of Mass Production and Custom Production. Davis (1987:169) defines the concept by suggesting that '*same large number of customers can be reached as in the ...**industrial economy**, and simultaneously they can be treated… as in … **pre-industrial economies**.'*. Pine (1993:48) more specifically defined mass customisation as the,

> '*...synthesis of the two long-competing systems of managements: the mass production of individ*ually customized goods and services.'

Therefore, mass customisation is understood as a production management system used to reach the low costs of mass production and variety of custom production through industrialised processes and economies of scope rather than economies of scale, as mass production (Pine, 1993:48; Noguchi et al., 2016a:100a; Tseng & Jiao, 1996:153). Accordingly, mass customisation is the synthesis of diverse aspects of mass production and Craftsmen, not only of production processes but in the conception of the market, design, communication, technology and social interactions (Toffler, 1980:293).

Accordingly, manufacturing systems used in mass customisation are also a synthesis or variations of the workbench-like and production-line organisation systems.

According to Bock & Linner (2015:137), there are other four additional manufacturing systems.

Workshop-like organisation— It refers to the manufacturing arrangement where the product flows between workstations. Times, sequence and flow are not fixed. Each station has a set of processes and tools bound to it (Fig. 27).

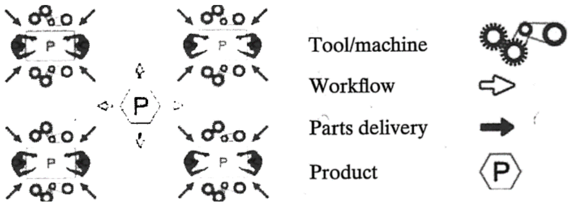


Figure 27. Workshop-like manufacturing organisation (From Bock & Linner, 2015:137).

Group-like organisation— It refers to the manufacturing arrangement where workstations with similar means are grouped together. The production flow first between the group workstations and then to other groups (Fig. 28).

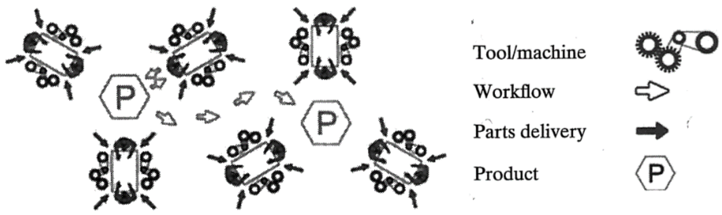


Figure 28. Group-like manufacturing organisation (From Bock & Linner, 2015:137).

Flow line-like organisation— It refers to the manufacturing arrangement where individual workstations do not have a fixed flow of material, but a general direction of flow of material is common (Fig. 39).

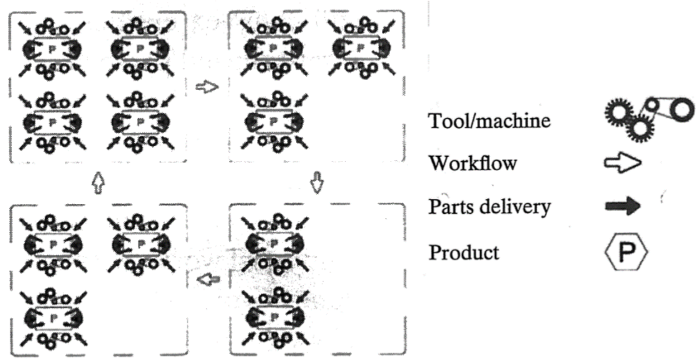


Figure 29. Flow line-like manufacturing organisation (From Bock & Linner, 2015:137).

Chain-like organisation— It refers to the manufacturing arrangement where workstations are fixed to a flow line, but cycle times are not synchronised. There are buffers between stations for storage and adjustment of production flow (Fig. 31).

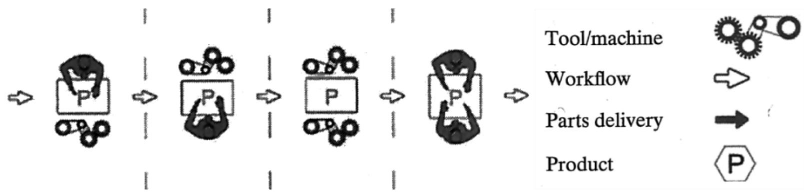


Figure 30. Chain-like manufacturing organisation (From Bock & Linner, 2015:137).

Agile and lean manufacturing

Agile and lean are manufacturing paradigms highly associated with mass customisation (Martinez et al., 2017:96; Naylor et al., 1999:97; Nahmens & Mullens, 2008:84; Naim & Gosling, 2011:343). Agile manufacturing particularly relates to the principles of customisation, as it is defined as the capability of surviving and prospering in a competitive environment of continuous and unpredictable change by reacting quickly and effectively to changing markets driven by customer-designed products and services (Gunasekaran, 1999:88).

The main objectives of agile manufacturing are to produce high quality and highly customised products with high information and value-adding content, have effective responsiveness to social and environmental issues, and response to change and uncertainty (Yusuf et al., 1999:36).

Lean manufacturing supports the development of mass customisation in reducing the impact of customer choice and productivity. Lean principles are not necessarily concerned with increasing product variety but are essential in balancing agile principles with cost-effective production (Nahmens & Mullens, 2008:97).

Lean manufacturing is defined as the manufacturing methodology that focuses on maximising production value and productivity through minimising of waste and inventory, quality control and continuous improvement from staff, suppliers and customers feedback (Stone, 2012:112-114; Nahmens & Mullens, 2008:99; Wilson, 2015).

Lean manufacturing management is built on two techniques; 'just-in-time' and 'total quality management'. Just-in-time refers to the technique of supplying exactly the right quantity at the right time, and exactly the correct location. It is quantity and variation control (Jasti & Kodali, 2015:868). Total quality management refers to the search for better quality through strict quality control systems and a series of techniques to improve and make production more efficient (Wilson, 2015).

Just in time is a technique used to achieve continuous pull productions, meaning stable production flows despite variability in production. In pull productions, it is vital to complete the product in times that satisfy the customer, also known as 'Takt' time. In production-line systems components are produced and carried across the production line continuously. It causes parts to accumulate and disruptions and risk of overproduction, which eventually results in waste of material and storage space (Fig. 31).

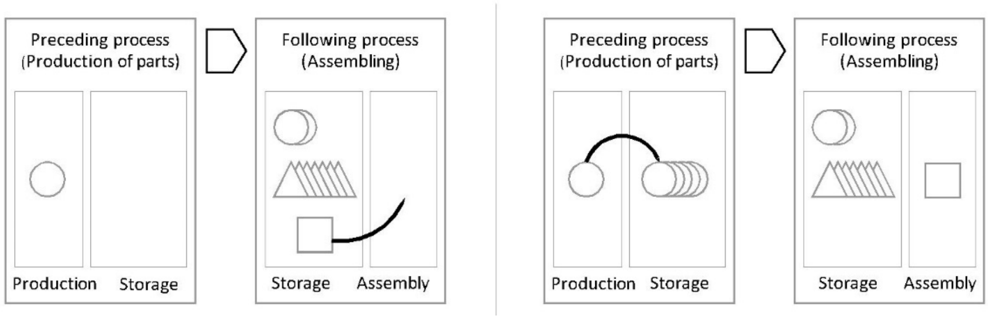


Figure 31. Mass production sequences of tasks (Diagram by the author).

In just-in-time production systems, the production line is divided into stages. Each production stage supplies the proceeding stages and obtains whatever needed from previous stages whenever needed. Thus, flow is ensured, while storage and waste are minimised, as production of parts is determined by the need of these on the following stages (Fig. 32).

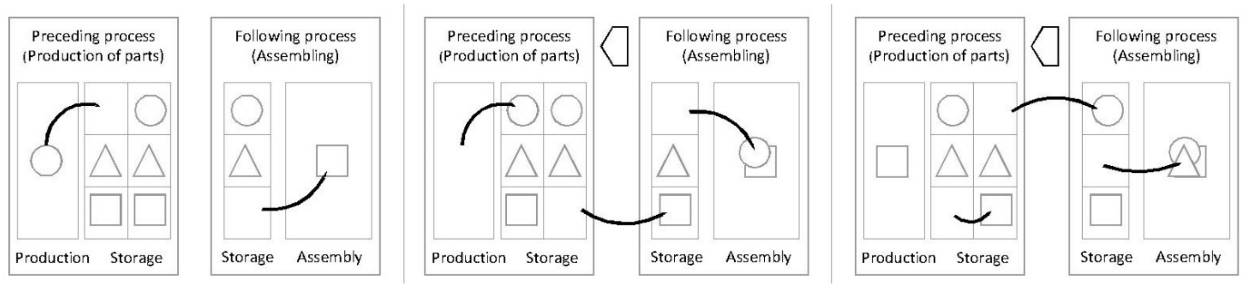


Figure 32. Just-in-time sequences of tasks (Diagram by the author).

Total quality management refers those techniques that empower human work and promote quality control, where human work is separated from mechanical processes done by machinery and production lines are stopped if defects are identified and do not restart until fixed (Gupta et al., 2013:243,245).

The lean production system is usually represented as an analogy of a 'classic temple' where the foundations are continuous improvement and stability through standardisation; just-in-time and total quality control are the two pillars that sustain the goal of highest quality at the lowest cost in the least time by eliminating waste (Fig. 33).

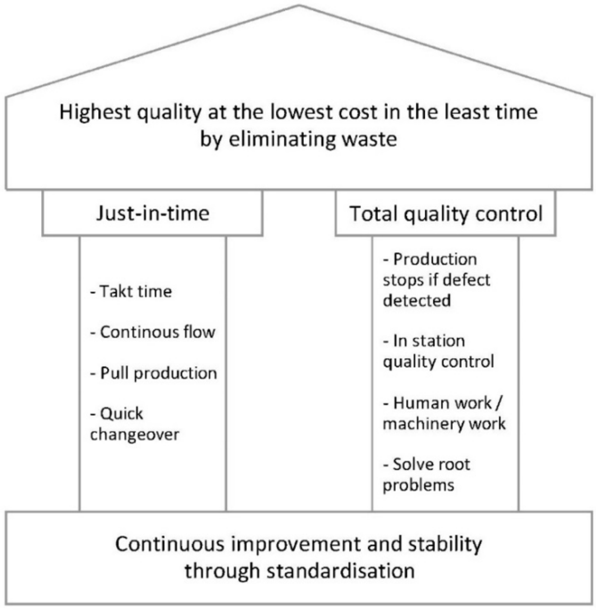


Figure 33. Lean manufacturing principles (Diagram by the Author).

Therefore, agile manufacturing enables customisation, while lean efficiency and high value. These paradigms are complementary to each other. The balanced use of both paradigms, also known as 'leagility' supports the implementation of mass customisation (Naylor et al., 1999:117; Nahmens & Mullens, 2008:99).

Pragmatic definition of mass customisation

The mass customisation term has been criticised for being ambiguous and paradoxical, causing not be used or applied as expected from such an alluring concept (Zipkin, 2001:81). Tseng & Jiao (2001:685) redefined mass customisation more pragmatically to relate the concept to production and logistics as:

'... a new paradigm for industries to provide products and services that best serve customer needs while maintaining near-mass production efficiency.'

Piller & Tseng (2010:1), in their 'Handbook of Research in Mass Customisation and Personalization', expand Tseng & Jiao definition to clarify that mass customisation is also a matter of marketing, management and service, which reads as follows,

'Along with Joseph Pine (1993), we define mass customization as "developing, producing, marketing and delivering affordable goods, and services with enough variety and customization that nearly everyone finds exactly what they want." What one needs, when one needs it. Or, to say it in a different way, mass customization aims at producing goods and services catering to individual customers' needs with near mass production efficiency (Tseng & Jiao 2001).'

Here, Piller & Tseng set their theoretical frame to Pine and Tseng and Jiao's conception to present pragmatic questionings and potential applications of mass customisation. Piller & Tseng (2010:1) continue their mass customisation definition by stating that *'To apply this apparently simple statement in practice is quite complex.'*. However, Piller (2004: 314,328-329) himself discuss that the ambiguity of these theoretical definitions is reflected in the scarce application of mass customisation in practice. Thus, Piller (2004:314) states that,

'…beyond these understandings[12]*, the term is used today for all kind of strategies connected with high variety, personalization, and flexible production'.*

12 Piller is particularly referring to the definitions established by Davis (1987), Pine (1993) and Tseng and Jiao (2001).

Piller (2004:314) suggested that the major problem is that mass customisation is possibly a '*buzzword*'[13] with no clear definition or common understanding, which interfere with its application in practice and research. Certainly, Piller & Tseng definition is confusing and does not represent mass customisation practice. For example, Piller & Tseng state that mass customisation allows the production of goods and services where *'nearly everyone finds exactly what they want'*. However, mass customisation, as a production process, has production limitations and can only produce a finite number of products; which is also valid for services.

As an example, Subway, McDonald's and Blaze Pizza are considered mass customisation services. These companies allow their customers to select from a menu of ingredients, size and forms and mixed them to their preferences. However, their selection is limited to the companies' predesigned menu (Calegari & Fettermann, 2018:24,27-28; Newman, 2015) (Figs. 35 & 35).

Figure 34. (left) Subway ingredient options (source Newman, 2015). Figure 35. (right) Pizza assembly line (source Newman, 2015).

[13] Piller refers to mass customisation directly as a 'buzzword'. Stan Davis (1992— In Pine, 1993:xii) also refers to mass customisation as a 'buzz' word; however he stated *'mass customization is not merely a buzz word or a tool, it is an expression of the future.'*.

Piller decided to update the mass customisation definition to relate the mass customisation concept to practical aspects, considering production and service limitations observed in practice. Thus, Piller (2004:314) redefined mass customisation as the,

> *'**Customer co-design process** of products and services, which meet the **needs of each individual customer** with regard to **certain product features**. All operations are performed within a **fixed solution space**, characterized by stable but still flexible and responsive processes. As a result the **costs associated with customization** allow for a price level that does **not imply a switch in an upper market segment**.'*

In this definition, Piller (2004:314) reveals that there are diverse concepts embedded that needs to be defined to conceptualise the term. Mass customisation is a complex paradigm and complicated practice because it needs that several elements work well together (Zipkin, 2001:81).

Mass customisation requires the involvement of the customer (end-user) during the production process. A product can only be produced after a customer chooses its characteristics. This implies postponement of production tasks, outcome uncertainty and manufacturing dependency to the customers' design decision. Thus, mass customisation is a process of 'co-design' because its design approach is based on collective creation; or as understood using business terms, as a design agreement between customer and producer (Thallmaier, 2015:11; Grafmüller et al., 2018:216).

In practice, the implementation of mass customisation relies on the ability to manage parallel processes; where the production capabilities determine the design variability but should adapt to new market demands, and vice versa (James & Mondal, 2019:638). There are many ways for companies to apply mass customisation, each with different implications for investment and degree of customisation.

From a mass customisation perspective, the application of any strategy used to solve the conflict of satisfying market demand without losing production efficiency is called mass customisation challenges. Piller and Tseng (2010:2-4) identify these challenges as production efficiency (speed and lead time), heterogeneity (customers' needs), economies of scale, value and complexity (Mukherjee, 2017:60; Piroozfar & Larsen, 2010:874-875). James & Mondal (2019:641,655-657) define the various parameters that affect production efficiency with the adoption of mass customisation strategies in twenty-nine categories. Among these, the following five parameters were identified as the more conflicting for manufacturers, in the following order.

- *Non-availability (breakdown and maintenance)*— This refers to the frequency of changeover, tool adjustments, machine optimisation, program change and tool wear.

- *Product process and organisational complexity*— This refers to the complexity of parts of product, product, process, program, layout, equipment and organisation. These complexities arise when production processes are flexible, versatile, interchangeable and combinatorial with other production processes. It requires sophisticated management and labour training.

- *Quality*— This refers to the changes on (quality) specifications of the product. Changing quality affect the processing speed, seen as a production inefficiency.

- *Setup time*— This refers to the time needed to set up production lines and supply chains, including cutting tool setup, program selection, fine-tuning and cutting parameter adjustments. The setups are sequence-dependent because they depend not only on the job that is to be processed next but also on the job processed just before.

- *Product variety*— This refers to the expected variability of production induced by the customer. It directly slows down production and implies postponement of production tasks. It also requires the design of a co-design process, including the translation of the customer decisions into production meanings.

Other parameters that affect production efficiency are leading times and dates, workforce, logistics, changes in material and changes in lot size. Each market has its challenges, and the application of mass customisation will impact differently in their costs, investments, delivery and customer approach (James & Mondal, 2019:680; Zipkin, 2001:84,87; Piller & Tseng, 2010:4-5).

Mass customisation capabilities

'Mass customisation capabilities' refers to the integrated organisational ways and methods to address the mass customisation challenges (Piller & Tseng, 2010:3-4). In other words, the mass customisation capabilities are the essential organisational elements required for the application of mass customisation in any production or service sector. Piller & Tseng (2010:4) categorise these in three fundamental mass customisation capabilities'; (1) Solution Space Development, (2) Robust Process Design and (3) Choice Navigation.

(1) Solution Space Development

The 'solution space' represents the *'pre-existing capability and degrees of freedom built into a given manufacturer's production system'* (Piller, 2004:316; Von Hippel, 2001:251). The solution space concept is a concept borrowed from algebra that refers to all possible solutions for the combinatorial optimisation problem. In other words, all the correct and possible answers that a mathematical or algebraic problem could have. From a production perspective, the solution space frames production extents of customisation.

In mass productions, customers are positioned at the end of the supply chain and *'They are sold whatever the production function produces'* (Pine, 1993:194). In contrast, in mass customisation, customers are bridged to the design/production decision-making process to allow them to decide the design and even the production characteristics of their products.

Therefore, in mass customisation systems, the buyer not only gets and consumes, but it is also an active participant in the production and consumption processes. The distinction between consumer and producer breaks down or blurs. In this sense, the buyer that integrate to design aspects, also known as a 'prosumer'[14] (Davis, 1987:106).

However, this customer's apparent control is, in reality, circumscribed on the parameters pre-established by the provider in what is called 'the solution space'. Thus, the solution space determines the universe[15] of outcomes that a producer intends to provide to their customers, and then within that universe, the specific product's permutations are provided (Piller, 2004:316).

Mass customisation does not mean to offer limitless choice but provide a choice restricted to options in the system's capacities (Piller, 2004:316). The consumer can manipulate design and production aspects but remains immersed in pre-established decision-making loops designed by the provider (Pine, 1993:194).

Accordingly, manufacturers and product providers need to develop appropriate solution spaces starting from the production capabilities but ensuring customer capability to understand and manipulate the customisation options; or as Piller & Tseng (2010:5) define it, as the 'playground boundaries' (Salvador et al., 2009:73; Grafmüller et al., 2018:215).

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[14] A 'prosumer' is a consumer who becomes involved with designing or customising products for their own needs. Toffler (1980:283) defines 'prosumer' as the people that consumed what they themselves produced. This research is not referring to 'prosumer as a well-accepted category for camcorders, digital cameras, VCRs, and other video playthings; or as the merge between 'professional' and 'consumer'.

[15] All possible product outcomes.

Grafmüller et al. (2018:222) divide the solution space development into two phases:

- *the initial solution space development*— the period before a product is launched into the market, in which a company defines all the product and service possibilities or variations that it would like to offer at the time of its launch.

- *the adaptive solution space development*— describes the period after the market launch and the competence to continuously adapt or improve an existing solution space to current customer requirements and market conditions.

According to Piller & Steiner (2012:8-9), the solution space development needs to create value via these three features, '*the fit (measurements), the functionality* and *the form (style and aesthetic design)'*, any of which can become the starting point for customisation.

Defining the solution space is a hard challenge for mass customisation companies. The importance of setting a solution space is to find the true extent of customisation to meet customers demand while ensuring production efficiency (Grafmüller et al., 2018:217; Tseng & Piller, 2010:4-5).

(2) Robust Process Design

The 'Robust Process' refers to the capability '*to reuse or re-combine existing organizational and value chain resources to fulfil a system of differentiated customers needs'* (Tseng & Piller, 2010:6; Grafmüller et al., 2018:215). The aim of designing robust processes aims to ensure that the production performance remains satisfactory even when some of its factors can vary (Grize, 1995:239). In other words, the capacity of a production process and organisational structures to be flexible and efficient at the same time (Hart, 1995:36).

Piller & Fabrizio (2012) identify the following three methods to accomplish a robust process capable of producing variable outcomes.

- *Postponement: Delayed product differentiation*— This method is characterised for the partitioning of the supply chain into two stages. First, a standardised portion of the product is produced since the beginning; while the differentiated portion of the product is produced until the end-user decide on its design. The product parts are pre-engineered to be compatible with each other. Thus, they are designed for completion at any stage.

- *Flexible automation & modular processes*— It refers to the ability of a system to be quickly and easily re-tasked to change product design (Dickerson, 2014). Flexible automation can work in complement to 'process modularity' approaches. Operational and value chains are segmented but linked to a specific source of variability in the customers' needs. Thus, different requirements can be served by appropriately re-combining these segments.

- *Adaptive human resources*— It refers to the capability of employees to deal with novel and ambiguous tasks to offset potential rigidities embedded in-process structures and technologies. In short, employees capable of developing diverse tasks to fulfil variable product outcomes.

A robust process allows systems to deliver with near mass production efficiency and reliability (Tseng & Piller, 2010:5). It could provide *'easier process control ... a wider range of applicability and higher quality.'* (Grize, 1995:239). Recalling that mass customisation is the ability to provide customised products and services without sacrificing efficiency, trade-offs in cost, delivery and quality (Sandrin, 2014:159; Noguchi et al., 2016a:95).

(3) Choice Navigation

'Choice Navigation' refers to the capabilities of a company to enable and support the customers to identify and customise their product by minimising complexity and burden of choice (Grafmüller et al., 2018:215; Tseng & Piller, 2010:5). In other words, it refers to the interface where customers explore and decide on the producer offerings (Salvador et al., 2009:74).

Mass customisation companies require to support, inform and simplify the customer's decision-making process; otherwise the values of quality, flexibility and even customisation can get lost (Tseng & Piller, 2010:5-6; Salvador et al., 2009:74). Tseng & Piller (2010:5) explain this phenomenon as follows.

> *'When a customer is exposed to too many choices, the cognitive cost of evaluation can easily outweigh the increased uti*lity from having more choices, creating the "paradox of choice": too many choices reduce customer value instead of increasing it…'

The 'paradox of choice', or as Toffler (1970:234) refers as the 'overchoice' dilemma, can *paralyse* the customer, making them postpone or suspend the buying process. Thus, supporting the customer is not only a successful business system ideal. It is needed to allow the completion of the consumption process (Tseng & Piller, 2010:5).

A clear example of an effective choice navigation design is the NIKEiD online customisation platform. In this, customers follow a design stepped process where they can select the type of shoe, colours and materials. Nike's solution space is ample; however, the customer only decides from less than ten options in every design stage. The following image shows the different stages of the NIKEiD navigation tool. First, customers select the shoe's type by sport. Then, they selected from a catalogue of predesigned models. Finally, they customise the elements by clicking on submenus of colours and materials (Fig. 36).

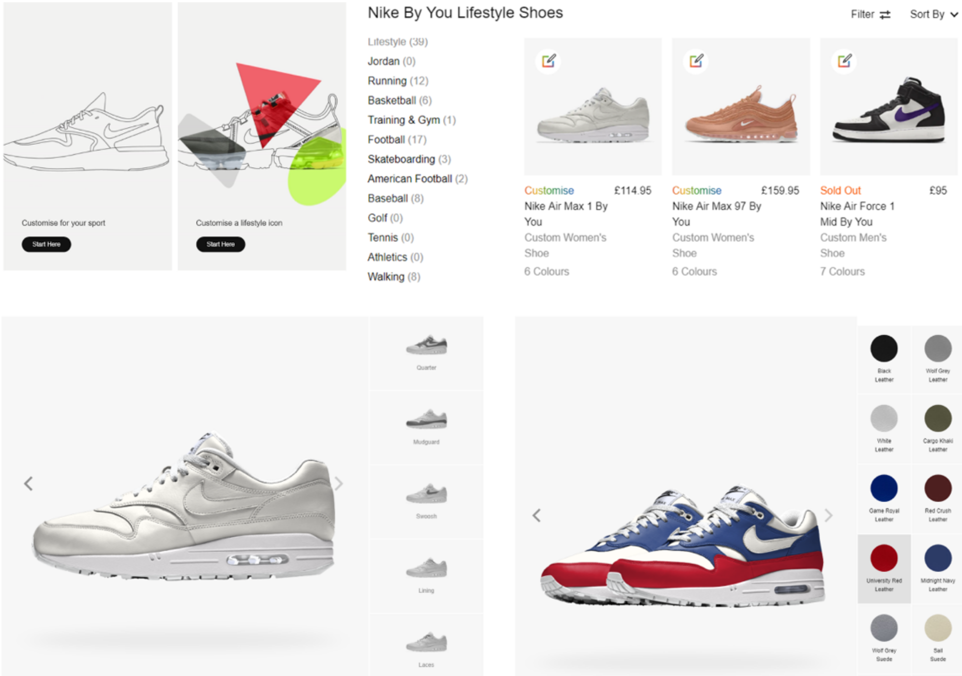

Figure 36. NIKEiD's customisation solution space from a customer perspective (by the Author from NIKEiD website.

Muji, a Japanese company, sell houses using a solution space that allows customers to select from three different house types. Then, the house dimensions can be modified by the customer by merely moving a corner of the displayed plan to the desired size that fits the plot. The user can only modify the plan in segments of half a meter. The floor dimensions are fixed, so when the ground floor is modified, the upper floor adjusts automatically to it. All openings, structural design, circulation spaces and stairs are also arranged automatically (Fig. 37).

Figure 37. Muji's customisation solution space from a customer perspective (by the Author from Muji Japanese website

An appropriate solution space for zero energy housing would allow customers to make multiple design choices but ensure that these decisions achieve a zero energy balance.

The following diagram shows the mass customisation capabilities— (1) Solution Space Development, (2) Robust Process Design and (3) Choice Navigation—in (Fig. 38).

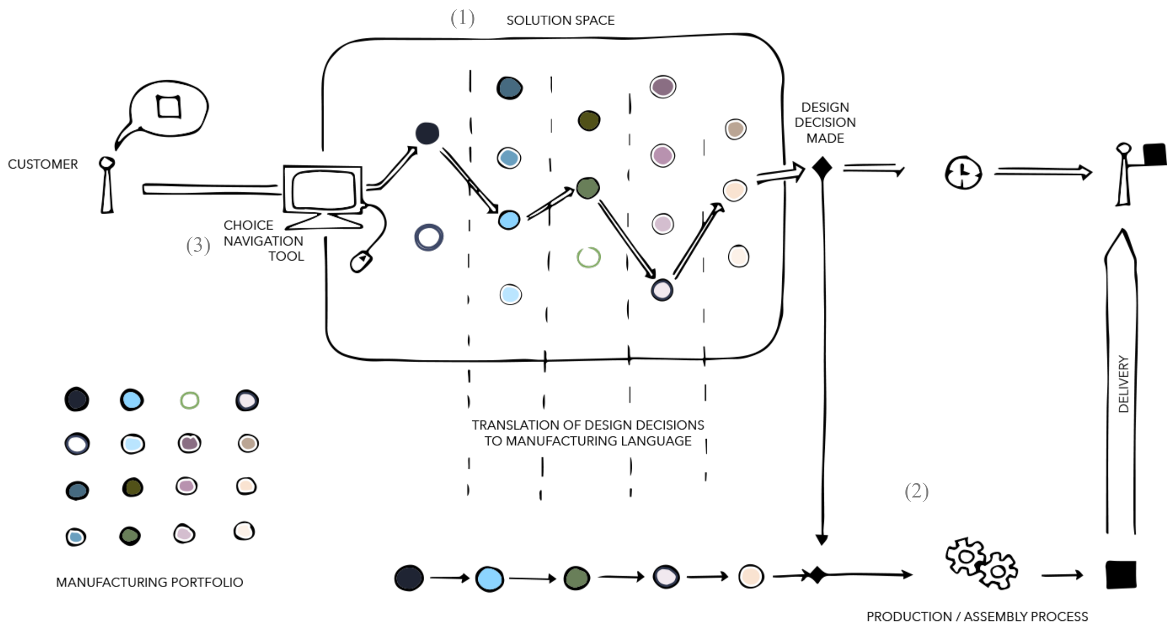

Figure 38. Nike's manufacturing current network (Diagram by the author).

Mass customisation enablers

The management of mass customisation and its capabilities require means, technologies or methodologies to be developed or implemented into a system—commonly known as 'Enablers' (Hart, 1995:41: Zipkin, 2001:84). 'Mass Customisation Enablers' are those processes, methodologies and technologies that support the development of the organisation-based factors that allow the conception of customisable products (Silveira et al., 2001:5; Fogliatto et al., 2012:17). In short, the enablers are the technological solutions for the implementation of mass customisation that assist in the managing of parallel processes (Piller, 2013:26).

Fogliatto et al. (2012:17) categorise the mass customisation Enablers into the following four categories: Methodologies, Processes, Manufacturing technologies and Information Technologies; which are described as follows.

- *Methodologies*— Organisational strategies and systematic methods that support the development of mass customisation (Da Silveira et al., 2001:5). These methodologies have a management stance. Examples of these are ‘lean production’ and ‘agile manufacturing’ (Spišáková & Kozlovská, 2013:88).

- *Processes*— Manufacturing strategies and methods that allow flexible production. It includes order elicitation, design postponement, design product platforms and supply chain coordination.

- *Manufacturing technologies*— Manufacturing machinery and technologies that allow controllable but customisable production. It refers to software, such as computer-aided design (CAD). Consequently, it should be considered as part of the manufacturing technologies.

- *Information technologies*— Those communication technologies that enable orders to be fulfilled correctly through the integration of information flows. It refers to the communication technologies used to coordinate suppliers, deliveries and all processes involved in the supply chains. These enablers also provide the means to integrate customers in the production process. They can share information automatically or analyse data and react accordingly. Their capabilities in the context of mass customisation are vast; both customers and companies can use them, they provide customer decision support but also assist in pricing, design, production planning and the gathering of production process information (Grafmüller et al., 2018:223).

The enablers change and evolve depending on technological advances and incorporation of the new organisational system (James & Mondal, 2018:641). The development of mass customisation capabilities requires the coherent implementation of enablers to each particular context and market, and its continuous updating (Piller, 2013:26-mass customisation-ARCH).

As an example, Building Information Modelling (BIM) is an enabler present in the architectural and construction sectors. It consists of files with information related to building, as drawings, plans and data, that is accessible and modifiable by multiple agents involved in a project (Rundell, 2005). The following image shows a project developed through BIM in Autodesk Revit, showing plans, facades, 3D views and all technical information needed for construction (Fig. 39).

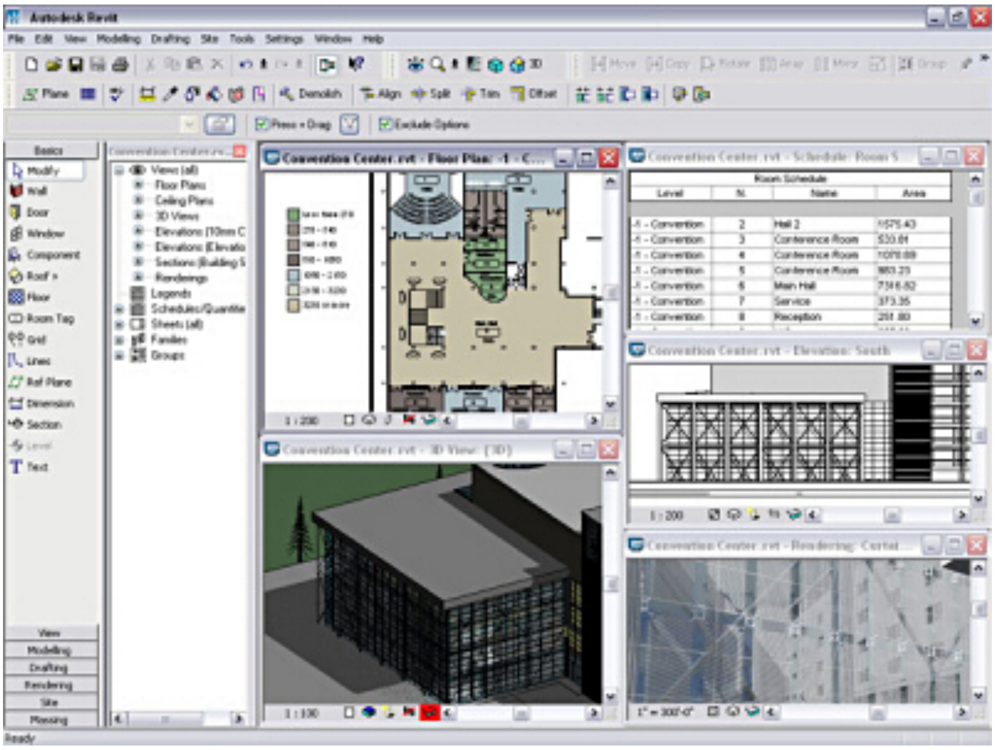

Figure 39. BIM project developed in Autodesk Revit (From Rundell, 2005).

BIM can be used as a choice navigation tool to present clients the project and make live modifications. Also, as a database where manufacturers and contractors specify their production capabilities; and thus, work as a solution space directory; alternatively it works as software to deliver the production decisions to manufacturers (Morton, 2014:18).

As an example, the ‘Da Vinci Huis’ is a BIM like virtual configurator developed by Hurks— a Dutch construction company— that allow its clients to customise housing projects. The clients (housing developers) can select architectural typologies, dimensions and add-ons like balconies or roof windows; and display cost and visualisation immediately (Bouw Connect, 2013). The following image shows how the Da Vinci Huis configurator can be used to customise housing developments (Fig. 40).

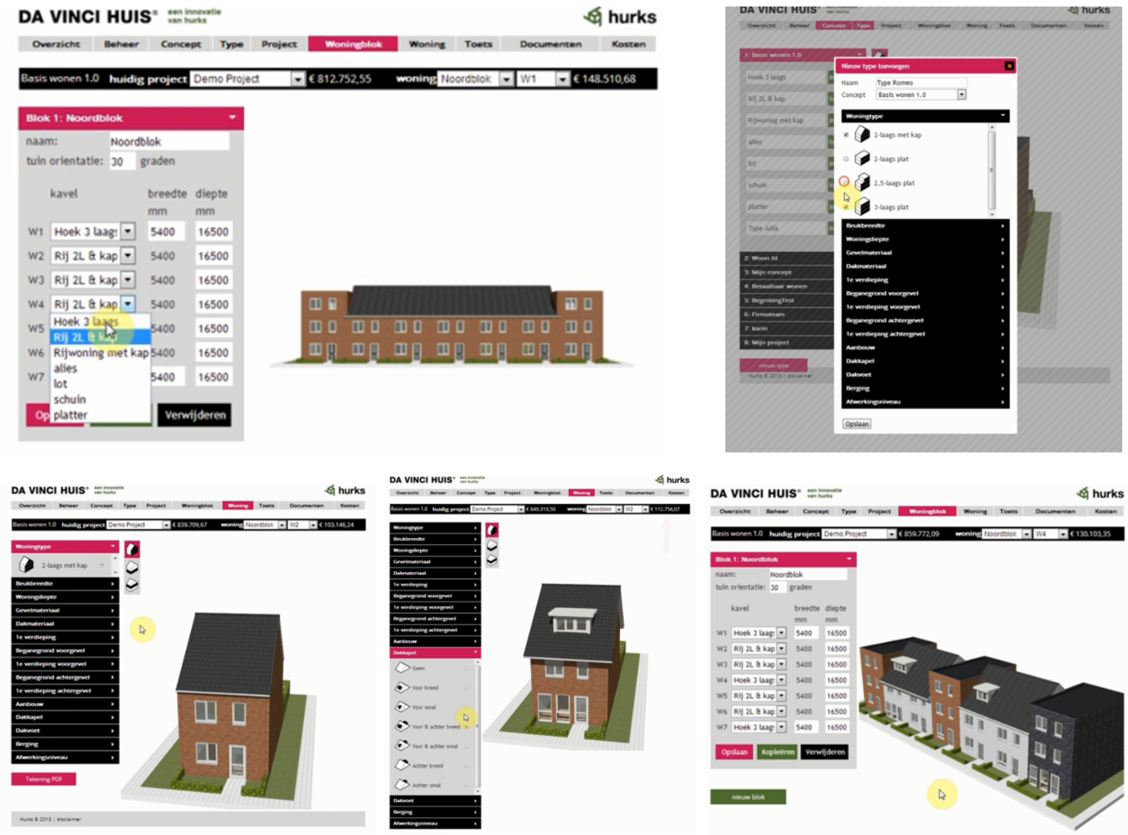

Figure 40. Da Vinci Huis Configurator (adapted from Bouw Connect, 2013).

The customisation process can happen at any stage of the supply chain and depending on that, the level and type of customisation vary (Silveira et al., 2001:2-3; Duray et al., 2000:610). This trade-off point between standardised production and customer's design decision-making is called 'Customer Order Decoupling Point' (CODP) (Rudberg & Wikner, 2004:447).

‘Customer Order Decoupling Point’

‘Customer Order Decoupling Point’ (CODP) refers to the point that separates decisions made under uncertainty from decisions made under certainty (Rudberg & Wikner, 2004:447; Mukherjee, 2017:64). The CODP is also known as order penetration point because as it refers to the breaking point between standardised and customised production (Daaboul et al., 2015:285; Xu, 2007:302; Schoenwitz et al., 2017:79; Can, 2008:29).

The CODP represents the customers’ involvement depth in the production process. Systems that have a CODP imply that their goods or services have a certain degree of co-design and customisation (Fogliatto et al., 2012:18). Thus, the CODP is the particular point, in a suspended linear, supply chain where at one end is the ‘supply perspective’ and in the other the ‘demand perspective’ (Rudberg & Wikner, 2004:446). The following image is an analogy of how the CODP moves between the supply and demand perspectives (Fig. 41).

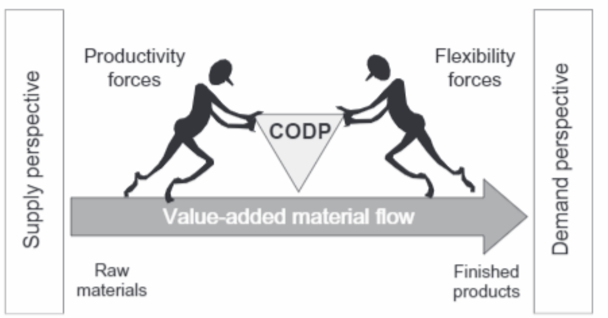

Figure 41. The productivity-flexibility trade-off and the positioning of the CODP (from Rudberg & Wikner, 2004:446—Figure 1).

The positioning of the CODP set the balance between productivity and flexibility. The closer the CODP is positioned from the supply perspective higher the customisability. Likewise, the closer to the demand perspective, the higher the production control (Rudberg & Wikner, 2004:446; Xu, 2007:304). Rudberg & Wikner, (2004:447,476) categorise seven types of processes depending on the level of postponement, and consequently, the location of the CODP, as follows:

- *Make to forecast*— All production and selling are standardised. This resembles any mass-produced product, as the Ford T model or Ikea.

- *Shipment to order*— All production is standardised, but local companies develop the distribution of the products. An example of this could be food consumables, as Coca Cola.

- *Packaging/labelling to order*— All production is standardised but labelling and distribution are developed individually. In this case, the same product is sold to the customer as different brands and with different costs. An example of this could be Moleskine notebooks, which are manufactured by a subcontracted company. This manufacturer is selling the same products to other companies, but branding them differently (Saner, 2012; Horowitz, 2004).

- *Final manufacturing/assembling to order*— All parts are produced by subcontracted manufacturers but assembled depending on customer specifications. NIKEiD customisation process works this way. All parts are mass-produced and then assembled according to the client's configuration.

- *Make to order*— The materials and components are standardised, but the rest of the production process is postponed for customer's decisions. An example of this is 'Carbon Dynamic', a Scottish housebuilder, that outsource CLT (Cross Laminated Timber) panels from other companies and assemble houses on their facilities. The CLT panels are delivered to Carbon Dynamic pre-cut to the dimensions and specifications of the client's project.

- *Buy to order*— This is when the product is predesigned, but the clients must specify materials and construction processes. The Da Vinci Huis allows clients to decide, even on the construction system; however, the design customisation is limited to menu choices.

- *Engineering to order*— Any bespoke service where the client specifies the design and production. Architectural firms usually provide bespoke housing services.

The following diagram exemplifies these categories organised from its level of customisation, which, according to Yang et al. (2004:476) are directly proportional to the level of supply chain postponement (Fig. 42).

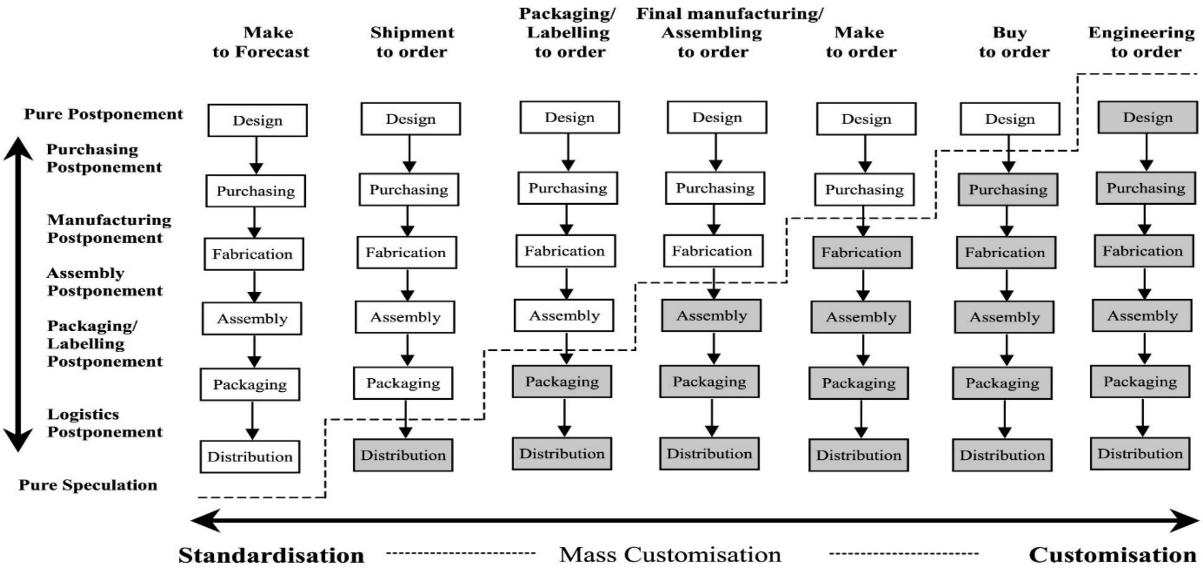

Figure 42. Customisation level determined by supply chain postponement (Source: Yang et al., 2004:476— Figure 1).

There is no ideal CODP positioning to achieve mass customisation. The mere inclusion of customers in the supply chain is enough to achieve a type of customisation. Each business determines their CODP, context, environment and companies' characteristics (Daaboul et al., 2015:293; Rudberg & Wikner, 2004:456-457; Yang et al., 2004:483). Rudberg & Wikner (2004:456) state that the successful implementation of mass customisation is critical and rests upon finding an appropriate mechanism that incorporates each customer's specification in the product design and manufacture.

Briefing mass customisation

This research identifies Piller's (2004:314) definition to cover the theoretical and pragmatic aspects of mass customisation broadly. Regardless, aspects related to the mass customisation capabilities, enablers and CODP should be included to complement this definition. Therefore, this research proposes the following definition for mass customisation.

> Mass customisation refers to the co-design processes of products and services that allow end-users to customise their products to certain limits.
>
> Mass customisation systems perform within three capabilities— Solution Space Development, Robust Process and Choice Navigation— that ensure stable but still flexible and responsive processes. The integral use of these capabilities allows dealing with the challenges raised from the mass customisation conception. The application of these capabilities requires the use of different enablers.
>
> There is no single approach to mass customisation. The type of mass customisation is determined by the type of market and the positioning of the Customer Order Decoupling Point, and thus, the selection of appropriate enablers and management strategies.

Sustainable benefits of mass customisation

Mass customisation production systems avoid material and energy wastage as these only produce the products that are already sold. As an example, the mass production shoe industry has a 20% unsold rate, which eventually transforms into waste (Boër et al., 2013:185-186).

Some mass customisation systems have shorter supply chains than mass production systems, which also results in energy savings (Boër et al., 2013:186-187). For example, IKEA— a mass production company— requires large storage areas (in factories and stores) and complex logistics of transportation from factories to storage areas and stores. In contrast, 'Unto this last'— an on-demand furniture company that use compact Computer Numerical Control (CNC) machinery to cut all parts needed for their products— possess a short and straightforward supply chain. Unto this last customers select a product from a menu, which then it is cut, assembled and delivered. Unto this last workshop and showroom is in London city centre and does not require a large area (Alter, 2006; carefullycurated, 2014) (Figs. 43 & 44).



Figure 43. Unto this last CNC machinery. Figure 44. Unto this last plywood board cut. Figure 45. Unto this last showroom and assembly workshop (from Unto this last website).

Additionally, mass customisation production is influenced by market tendencies; thus, if sustainable demand increases the production of sustainable products will consequently increase (Boër et al., 2013:189-192).

These factors are also present in the housing industry. mass customisation is considered a catalyser to produce sustainable housing, including zero energy dwellings. Noguchi & Hadjri (2010:907) explain this as follows.

> *'The notion of sustainable development tends to link the collective aspirations of the world's people for improved living conditions and a healthy environment with the need to reconcile conflicting perspectives on the economy…. The homebuilding industry is no exception and builders today are requested to deliver homes that correspond with the social, economic and environmental sustainability targets. Mass customization was considered the effective means to create options from which users can choose. User choices are critical in how a house is designed, constructed and operated. Without the user participation, homes may never achieve the sustainability agenda.'*

Thus, mass customisation works as a booster for energy-efficient features and sustainable design strategies. Noguchi & Hadjri (2010:907) continue by stating that mass customisation, referring to the interactive selection of architectural elements, '*encompass the design principles rooted in inclusive design approaches, affordable housing strategies, passive solar techniques and active renewable energy technologies… that help achieve sustainability goals.'*

Mass customisation and zero energy: compatibilities and contradictions

In principle, mass customisation relates to sustainability because it is a more efficient process when compared to mass production. In terms of sustainable housing, mass customisation is presented as a solution to cope with arising conflicting social and economic demands present in the built environment (Noguchi, 2016:v; Zero Carbon Hub, 2009:6). Piroozfar & Piller (2013:4) describe this phenomenon as follows.

> *'Stakeholders in the built environment are being forced at an extensive and unprecedented pace to improve a set of conflicting objectives. On one hand, they want to enhance the cost efficiency and economic sustainability of their constructions. On the other hand, the market demands that the functional performance, indoor quality, comfort levels and social sustainability of the buildings shall be increased. And at the same time, building professionals concentrate on the reduction of energy consumption, the ecological footprint of a building process and its carbon emission, boosting the environmental sustainability. ...This apparently conflicting set of goals demands a new industrial paradigm... mass customisation emerged… as a paradigm for exactly this purpose — offering highly customised products with mass production efficiency.'*

Here, Piroozfar & Piller explain that mass customisation could help the housing industry to provide sustainable housing without sacrificing efficiency because production quality improvements, such as functional performance, indoor quality, reduction of energy consumption and provision of renewable technologies are market rising demands (Noguchi, 2013b:167-172). Thus, mass customisation creates value not only to the customers but to the companies (Piller, 2004:329).

Noguchi et al. (2016:116) explain the relation of mass customisation with the marketing of energy-efficient housing features as follows.

> *'Today, mass customisation has been devised in the context of housing, where the functionality and performance of the resulting*

> *home can be pre-selected or pre-determined by user-buyers' direct choice of standardised design components proposed, which also helps to define the desired and expected product quality achievable within the end-user's economic constraints'*

Therefore, mass customisation relates to zero energy as a strategy to cope with the market niche of zero energy houses. Mass customisation allows housebuilders to provide zero energy options that adjust to the customers' wants, needs and budget. Housebuilders' solution space also needs to adjust to different locations, climatic conditions, microclimates and orientations to provide design solutions that accurately achieve zero energy levels. Mass customisation systems can use effective enablers and navigation tools that adjust the solution space according to the site. Thus, mass customisation can work as an integral part of the design process. In addition, mass customisation— as a marketing strategy— can encourage the consumption of zero energy houses (Schoenwitz et al., 2017:85-87; Zero Carbon Hub, 2009:22-23).

However, there is an apparent contradiction between mass customisation and zero energy. In one side, zero energy set a strict boundary of how buildings reach an energy balance; while on the other hand, mass customisation is about expanding the customer's choices. Therefore, it is important to recall that mass customisation does not provide endless choices. mass customisation solution spaces are limited. Companies can limit their solution spaces in accordance with their production capacity, but also to fit a market niche. Housing, as any production practice, is driven by economics and marketing (Bardakci & Whitelock, 2003:477-479; Gilmore & Pine, 1997:91,96; Zipkin, 2001:85; Tseng & Piller, 2010:5).

Housebuilders could opt for mass customisation systems and restrict their offer zero energy dwellings as a business and marketing strategy. Their market scope would then focus on producing variable dwelling types but ensuring that all the options reach zero energy.

Redefining ZEMCH

ZEMCH, as coined by the ZEMCH Network, refers the acronym of Zero Energy Mass Custom Home. The meaning of ZEMCH, as a concept, needs to be compound into a single definition rather than a series of concepts listed together. Accordingly, ZEMCH can be defined by aligning the definition of mass customisation to the definition of zero energy dwellings. Thus, ZEMCH would be defined as,

> the mass customisation service that enables house-buyers to customise their dwellings, ensuring that these will generate enough energy on-site over a year to supply all expected on-site energy services.

Though, mass customisation cannot be fixed to a single definition as it as a concept that involves processes of management, production and marketing. Piller (2004:329) describes mass customisation multiple meaning as follows.

> *'Mass customization is… first of all a vision. A vision to perform a company's processes in a truly customer-centric manner, resulting in products or services that are corresponding to the needs and desires of each individual customer, and doing this without the surpluses traditionally connected with customization. There are*

> *many ways to make this vision a reality, and it seems especially true in a field like mass customization that there is not "one best way"..., but many paths to success, customized to the particular situation of one company and its customers in one market.'*

Therefore, ZEMCH should be defined on more pragmatic grounds, meaning on how housebuilders can use mass customisation to achieve zero energy dwellings. In this sense, ZEMCH is defined as,

> the mass customisation process that enables the provision of zero energy dwellings through a defined solution space that runs in accordance to the company's production capacity; in which house-buyers can choose certain design aspects using choice navigation tools that present the benefits of the choices made.

It could also be defined from a service perspective, where ZEMCH would be defined as,

> the service system designed to sell and market zero energy dwellings through mass customisation processes; in which the solution space is designed in accordance to the company's production capacity and uses choice navigation tools that facilitate house-buyers to customise their dwellings, restricting their choices to zero energy options.

These three definitions coincide on defining ZEMCH as a mass customisation process, which different to conventional processes of mass customisation, limits the production and provision of zero energy dwellings.

'Zero Energy Mass Custom Housing' in practice: Japanese house manufacturers

Today, Japanese housing manufacturers lead the commercialisation of zero energy and 'Zero Carbon' houses (Naim & Barlow, 2003:601; Barlow & Ozaki, 2005:13,17; Barlow & Ozaki, 2001:17,25; Johnson, 2007:27; Zero Carbon Hub, 2009:30-31). These housebuilders are highly recognised for the use mass customisation (Noguchi et al., 2016b:339; Noguchi, 2013b:166-167; Noguchi & Hadjri, 2010:898,903; Bardakci & Whitelock, 2003:471; Davis, 1987:158; Knaack et al., 2012:54-55; Piroozfar & Piller, 2013:7; Iwashita, 2001:295). Bock & Linner (2015:222) express that Japanese housing industry is one of the best examples of mass customisation as follows.

> *'... Japanese [large-scale prefabrication housing industry] meets the requirements of real and affordable mass customisation... [they use] demand-oriented manufacturing systems that by far exceeds the current ability to mass customize in automotive manufacturing.'*

Interestingly, in Japan, the term mass customisation is not commonly used. Despite that, they are among the most reliable manufacturers and service providers of individual customer-oriented products. Mass customisation appears to be deeply woven into the Japanese organisational culture and service thinking, which might impede them using in their everyday language or as a topic of scientific concern (Linner & Bock, 2013:155; Pine, 1993:104; Davis, 1987:158; Davies, 2005:188).

Lean manufacturing, and consequently mass customisation, have their roots in the Japanese culture. The lean paradigm is a conceptualisation of the 'Toyota Production System', which in turn is the merge and adoption of cultural concepts applied to manufacture management. The Toyota Production System was developed by the Toyota company between 1948 and 1975 (Wilson, 2015; Shmula, 2017). It was developed from Japanese traditions, such as *mottainai*—interest in waste reduction and efficiency— *kaizen*— change for better or continuous improvement— *heijunka*— balancing— and *jidoka*— autonomation— this last one being a synonym of total quality management (Stone, 2012:121; Nahmens, 2007:33; Nahmens & Mullens, 2008:83; Gupta et al., 2013:245).

Toyota implemented the Toyota Production System for the production of houses in the 1980s when Toyota Homes was founded. Eventually, other house manufacturers developed lean systems based on the Toyota Production System (Bock & Linner, 2015:114; Aitchison, 2018:63,93-95; Smith, 2009:178).

Examples of Japanese house manufacturers that use mass customisation are Sekisui House, Daiwa House, Pana Home, Sanyo Homes, Asahi Kasei / Hebel House Homes, Misawa Homes, Mitsui, Tama Home, Muji House, Sekisui Heim and Toyota Home (Bock & Linner, 2015:149). None of these companies restricts their sales only to zero energy or zero-carbon houses; however, they brand themselves as zero energy house providers. These housebuilders can offer the clients to restrict their options to zero energy houses. Some Japanese house manufacturers, as in ZEMCH Network, use the word ‘Home’ to name their companies as a branding strategy, as it is a term connected to social ideals (Blunt & Dowling, 2006:100-101,132).

Conclusion

This chapter focused on defining ZEMCH as a single concept rather than as an acronym of different terms. The argument of this chapter was composed using texts produced by the ZEMCH Network, an interview with Masa Noguchi, related literature review; and exemplified through a series of examples in practice.

In order to define ZEMCH, the terms of mass customisation and zero energy were defined. The ‘zero energy’ concept was analysed concerning its applicability in the built environment. Zero energy was identified as a threshold rather than a balance and was defined as follows.

- *‘Zero Energy Dwelling’* refers to those energy-efficient dwellings that generate enough energy on-site over a year to supply all expected on-site energy services for the dwelling users.

The zero energy concept requires the specification of the following factors to have practical use; energy balance, grid connection, metric or balancing indicators, balancing period, balance type, energy usage coverage, generation type, and spatial boundary and generation location.

The ‘mass customisation’ definition in this chapter was constructed from existing theoretical definitions but in relation to the housing practice. Thus, mass customisation was defined as follows.

- *‘Mass Customisation’* refers to the co-design processes of products and services that allow end-users to customise their products to certain limits, performed within the enablers and capabilities— Solution Space Development, Robust Process and Choice Navigation— that ensure stable but still flexible and responsive production processes.

In order to define ZEMCH, the ‘Home’ term, as ‘H’ in the ZEMCH acronym, needed to be addressed. Home is identified to have subjective interpretations; therefore, it was avoided when referring to dwellings.

It is implicit that mass customisation is an integral part of ZEMCH. Therefore, ZEMCH could refer to a service or a process. Accordingly, ZEMCH could not be fixed to a single definition. This chapter defined ZEMCH in the following three ways.

- *ZEMCH* refers to a mass customisation service that enables house-buyers to customise their dwellings, ensuring that these will generate enough energy on-site over a year to supply all expected on-site energy services.

- ZEMCH refers to a mass customisation process that enables the provision of zero energy dwellings through a defined solution space that runs in accordance to the company's production capacity, in which house-buyers can decide on certain design aspects using choice navigation tools that present the benefits of the choices made.

- ZEMCH refers to a service system designed to sell and market zero energy dwellings through mass customisation processes; in which the solution space is designed in accordance to the company's production capacity and uses choice navigation tools that facilitate house-buyers to customise their dwellings, restricting their choices to zero energy options.

In practice, the Japanese housing manufacturers leads to the commercialisation of zero energy dwellings and the use of mass customisation systems. The apparent coincidence of both zero energy and mass customisation present in the Japanese housing context suggests the potential of ZEMCH in other contexts.

Housebuilders in the UK could adopt mass customisation strategies observed in the Japanese housebuilding context to raise the energy efficiency levels of their products. However, as *'There is no **perfect** state of mass customisation'*; housebuilders that pretend to incorporate mass customisation needs develop their capabilities— solution space, robust design and choice navigation— with their contexts (Piller, 2013:26).

The following chapters would examine the house building scenario of Japan and the UK to determine how does mass customisation could be applied in the UK context.

Chapter 4

Contextual comparison: Japan is Japan, and the UK is the UK

This chapter presents a comparison between Japan and the UK housing contexts. It starts with a historical review of the housing strategies of each country from the end of the Second World War until the present. It then, describes the different conditions of each country and how these affect the land distribution, availability and housing models. It continues by explaining the differences in their planning systems. It also compares the different housing needs of each context. It finishes by describing the legislation related to energy consumption in households and how this affects the housing practice.

Introduction

There are substantial differences between the Japanese and the UK housing contexts. It is important to understand which aspects of the Japanese housebuilding practice are exclusive to its context to identify which aspects have the potential of being applied in the UK. Accordingly, it is essential to identify which aspects of the UK housebuilding practice are exclusive to its context to identify the aspects not suitable for implementing mass customisation strategies observed in the Japanese context (Barlow et al., 2003:143; Barlow et al., 2001:45; Johnson, 2007:41; Pan et al., 2008:17).

This Chapter describes and compares UK and Japanese contexts through a literature review to infer what has determined their current housing procedures, processes and business models. It focuses on the aspects that relate to the production of industrialised and mass customisation housing. This description is divided into four sections:

(1) *Historical comparison of housing from postwar times to the present day*– a description of housing strategies and events of Japan and the UK from 1945 to current times. It centres on the production of housing through industrialised methods regarding the economic crisis, and political and legislative interventions. Both contexts had similar housing needs after the Second World War and used similar housing strategies to cope with it.

(2) *The Land effect on the housing processes*— a description of the differences in land use and land conversion, explaining how this affects housing procurement. It includes the demographic and socio-economic status of Japan and the UK.

(3) *Legislation and Planning*— a description of the planning systems in Japan and the UK and its effect on the housing market. It explains the Japanese land constraint due to geographical conditions; while in the UK land availability is restricted by planning systems.

(4) *Housing need*– a comparison of housing starts with demographic and socioeconomic conditions of both contexts. It includes trends related to housing practices in both countries, including dwelling life, transaction market, ownership, supply and demand and housing prices.

(5) *Impact to energy efficiency*— a comparison of energy legislation between Japan and the UK; and a description of how Japanese manufacturers have responded with the production of highly energy-efficient products. It includes a chronological description of the UK legislation concerning domestic energy;

the characteristics of the Japanese domestic energy legislation; and the current average consumption and costs of energy (electricity and gas) in Japan and the UK.

Historical comparison of housing from postwar times to the present day

After the Second World War, Japan and the UK needed housing to recover from the urban destruction produced by the war. Both countries initially opted for the industrialised process to overcome their substantial housing deficits (Pawley, 1971:45-62). However, only Japan maintained a high percentage of its housing production through industrialised processes (Buntrock, 2017:190-191,199).

Despite presenting similar conditions in the first decade after the Second World War, the history of housing in Japan and the UK has followed opposite paths. These differences have been reflected in the housing volume that both countries have had during the years. The following graphic shows the housing completion in Japan and the UK from 1945 to 2015, where it is seen that Japan has produced significantly more houses (Fig. 46).

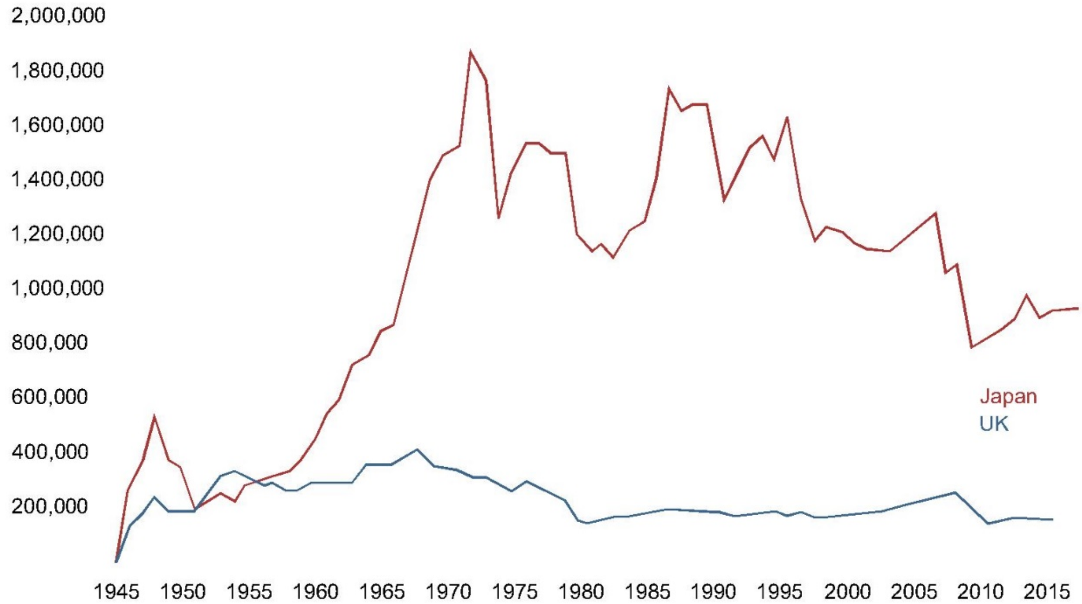

Figure 46. Housing completions in Japan and the UK since 1945 (diagram by the author with data from Johnson, 2007:10 and Jefferys et al., 2014:6-7).

Postwar recovery

In the years following the Second World War, both countries had a severe need for housing caused by the destruction of their cities during the war.

By 1945, Japan had 63,000 hectares across 115 cities in ruins with 2.3 million destroyed houses, and with *colonisers*[16] coming back to the country, Japan had a shortage of 4.2 million houses. Destruction account for over 30% of their urban environment and most of them suffered over 50% destruction. Parts of Greater Tokyo, like Fukuyama, suffered over 80% destruction (Koolhaas & Obrist, 2011:74-76). The

[16] Colonisers refer to the Japanese troop soldiers sent to occupy countries during the Japanese colonial empire from 1895 to 1945.

following image shows the level of urban destruction suffered in Japan after the Second World War (Fig. 47).

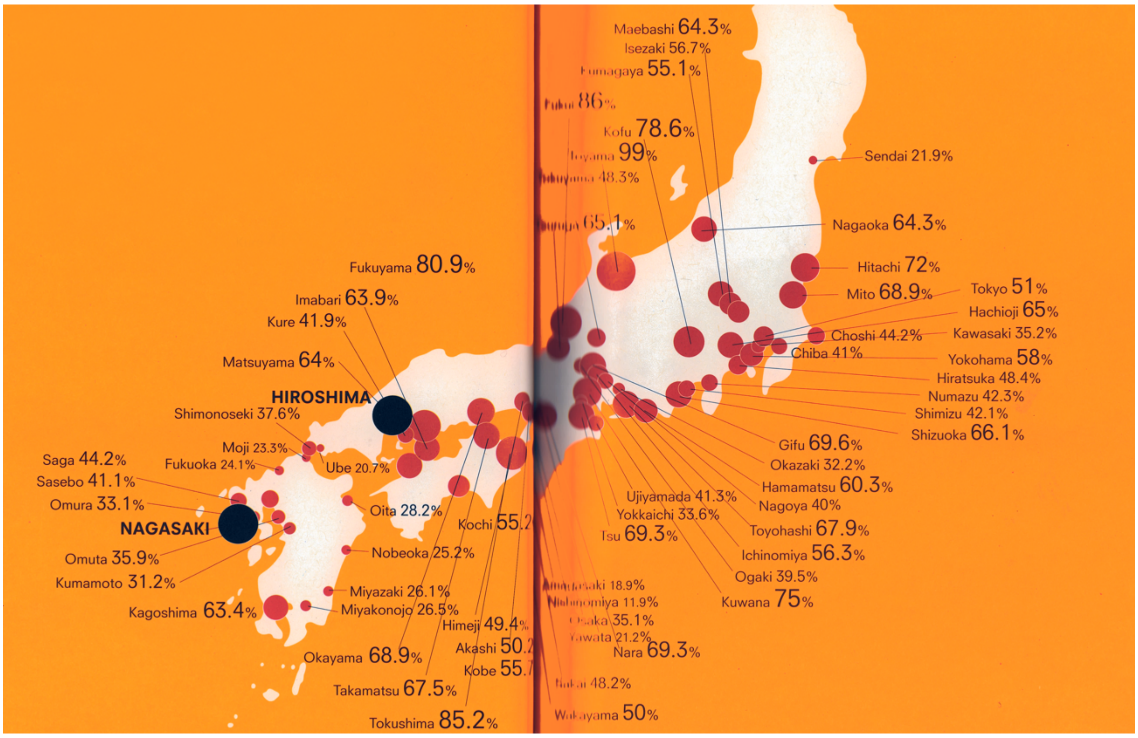

Figure 47. Level of urban destruction in Japan after the Second World War (from Koolhaas & Obrist, 2011:76)

The Japanese economy was unsteady, materials and labour were scarce, and supply chains were non-existent (Buntrock, 2017:190). Therefore, most of the houses built in Japan between 1945 and 1950 were self-constructed using residual war material, without the intervention of housebuilders. Governmental efforts and policies were focused on rebuilding the national economy while sacrificing housing recovery, influenced by external occupation (Knoroz, 2017:19; Waswo, 2002:47-50). From 1947 to 1948, the ‘Priority Production System’ took place in Japan that consisted of a policy to concentrate scarce resources into strategically selected industries, which did not include housing. The Priority Production System was implemented with the idea that '*limited resources must be selectively used for restarting an expansionary reproduction cycle*'. Therefore, most of the resources were input to the coal and steel industry (Ohno, 2017:153,163). Consequently, the first prefabricated houses in Japan were made of steel and produced by the steel industry.

In contrast, the UK had industrial capacity and resources to set an immediate housing programme (Blanchet & Zhuravlyova, 2018:25-26; Davies, 2005:61).

The UK programmes of prefabricated housing

In 1944, the UK government launched the 'Temporary Housing Programme' for the construction of over 155,000 prefabricated bungalows, also known as 'Prefabs'. The Prefabs produced during the Temporary Housing Programme were standardised houses produced entirely in factories. The Prefabs were subsidised by the 'Ministry of Works' and manufactured by private companies, which were active manufacturers not previously involved in housing, some of them were involved in the military industry (Vale, 1995:1-2; O'Neill & Organ, 2016: 206-210). As an example, the 'British Iron and Steel Federation' (BISF)— a company formed in 1934 provided steel through Second World War— produced 36,000 houses from 1941 to 1947 (O'Neill & Organ, 2016:12-16; White, 1965:39). The following image shows the positioning of an 'AIROH'— which stands for 'Aircraft Industries Research Organization on Housing'— Prefab house manufactured by 'The Bristol Aeroplane Company Limited' (Fig. 48).

Figure 48. AIROH Prefab house lowered into place. (from Potter, 2017).

The Prefabs were initially promoted as temporary housing as a political strategy used to increase the public acceptance of unconventional means (Davies, 2005:61).

Parallel to the Temporary Housing Programme, the Ministry of Works invested in the construction of permanent houses built with industrialised construction systems, also known as ‘non-traditional construction systems. Different from the Prefabs, these houses were assembled on-site using prefabricated components and commissioned to private contractors; where some of these were imported (Blanchet & Zhuravlyova, 2018:47,58). There were multiple non-traditional construction systems; Wimpey No-fines, Easiform, The BISF, B1 & B2 Aluminium bungalows, Cornish Units, Airey, Reema Hollow Panel, Wates, Trusteel Mk II & 3M, Unity, Frameform and Quickbuild. Approximately 1,000,000 houses have been constructed in the UK using non-traditional construction system, which few remain in production (Ross, 2002:10-11). The following images show the BISF house and Cornish houses, examples of non-traditional construction systems (Figs. 49 & 50).

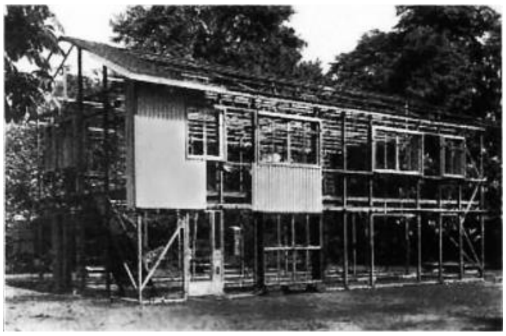 

Figure 49. BISF house under construction (from Potter, 2017). Figure 50. Cornish Units Type 1 (photo by Steve F. under Creative Commons Licence).

Accordingly, between 1945 and 1951, 89% of the houses were built by local authorities using highly industrialised construction systems. However, in 1949, as part of the ‘Housing Act’, the Temporary Housing Programme was cancelled to give way to the private sector, which was not allowed to build houses for the ‘working class’ until that date (Vale, 1995:1; Stevenson, 2003:7; Balchin, 1998:10). The Prefab production was dependant on government support, so once the programmes finished, the manufacturers based in the UK stopped producing houses and focused on producing for other sectors.

The birth of Japanese house manufacturing industry

In the 1950s, the Japanese economy was rising due to economic support from the USA, which was focused on strengthening the industrial sector (Kiprop, 2018). With the industry sector recovered, the Japanese central government enacted housing policies to set up post-war housing reconstruction— named the ‘three pillars’, which went into action in 1950, 1951 and 1955— to use housing development to drive economic growth (Zhang, 2017:45).

Consequently, manufacturers invested in the production of prefabricated housing. Daiwa House began producing houses in 1955, PanaHome in 1959 and Sekisui House in 1960; all of which were funded as spinoffs of existing Japanese manufacturing companies and are still active today (Buntrock, 2017:190; Noguchi et al. b, 2016:342; Gann, 1996:443; Johnson, 2007:6).

The houses produced during the 1950s were austere steel frame boxes, usually covered with aluminium cladding. These houses were small without water or gas installations and with little or no insulation materials. These were of lower quality when compared to the UK Prefabs (Aitchison, 2018:93; Bergdoll & Christensen, 2008:34). The quality was deficient because the demand was very high and people were living in poor conditions, where any shelter was appreciated. Japanese manufacturers respond to the circumstances by mass-producing houses, as an effective way to achieve high production at low prices. The following images show two of the early housing prototypes produced by Daiwa House in the 1950s, including its marketing pamphlet (Fig. 51).

Figure 51. Daiwa House's 'Midget House' 1959 prototype. (Source: Aitchison, 2018)

The production of prefabricated houses characterised the postwar recovery era in both countries. In the UK, the prefabrication of housing was coordinated by the state, resulting in quick and high production of houses, with enough quality to remain standing in the present day. However, the economic dependency on governmental funding and procurement limited house manufacturers to the length of the housing programmes (Ross, 2002:11).

In contrast, in Japan, the prefabricated houses were built by the private sector. Rising manufacturing companies create spinoff housing business to profit from the high housing demand. Their houses were mass-produced because of these were produced by manufacturers (Aitchison, 2018:93; Yamada, 1999:106).

The Japanese state proved unable to satisfy the housing need. The 'Japan Housing Corporation' (JHC) was established in 1955 to act as a prime housing provider, building a series of multi-storey buildings with flats, known as *danchi.* The JHC planned to provide 300,000 emergency shelters in one year but only built 43,000, counting only for 27% of all housing and 8% of rental housing, leaving 67% to the private sector (Knoroz, 2017:25-29).

Thus, in the decades of the 1960s and 1970s, the Japanese manufacturing sector continues expanding. Manufacturers dabble into the housing industry, either as housebuilders or manufacturer of housing parts and components (Yashiro, 2014:21). The following image shows the number of shipments produced by manufacturers involved in the housing industry during the 1960s (Fig. 52).

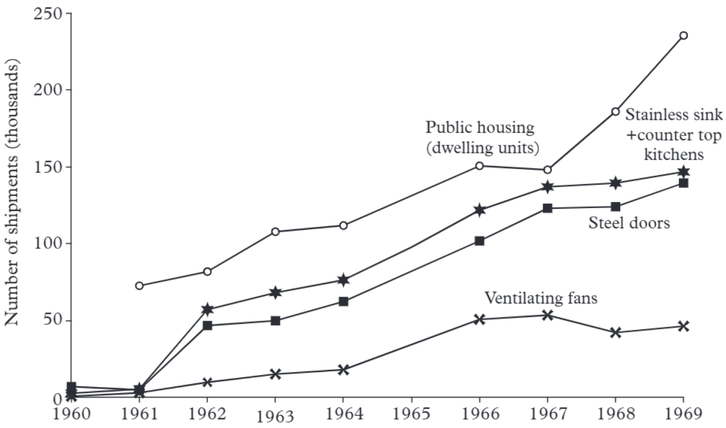

Figure 52. Number of shipments produced by manufacturers in the housing industry during the 1960s (From Yashiro, 2014:22— Figure 1).

Japanese house manufacturing industry consolidation

During the 1960s, the Japanese government continue supporting the industrialised housing sector with initiatives and promotion of the 'Housing Loan Corporation' and 'Japan Prefabricated Construction Suppliers and Manufacturers Association' (Duncan, 1973:62; Johnson, 2007:20; Barlow and Ozaki, 2005:12). In 1964, the 'Japan Prefabricated Construction Suppliers and Manufacturers Association' was funded; which, as an example, provided over six million pounds to Misawa Homes to develop low-cost, lightweight autoclaved ceramic components (Buntrock, 2017:190-191).

More house manufacturers were established in these years. Misawa Homes in 1962, SANYO Homes in 1969, Sekisui Heim (Chemical) in 1970, Asahi Kasei in 1972, and 'Toyota' in 1975 (Buntrock, 2017:190-191; Noguchi et al. b, 2016:342, 354-357; Gann, 1996:443; Johnson, 2007:6,13). None of which were established by housebuilders. A lumber supplier started Misawa. PanaHome's parent company, Matsushita, produced household electronics. Sekisui Heim spun off Sekisui House.

Toyota house spun off Toyota Motors, which in turn, spun off a looming manufacturer (Shmula, 2017). The Japanese government encouraged the emergence of factory-based housing industry; not only to cope with the housing need, but also with construction labour shortages (Buntrock, 2017:190-191).

In the early 1970s, Japan declared that the housing shortage carried from war times came to an end (Knoroz, 2017:25-29). From that point, the government focused on improving the housing quality by giving incentives and funding to practices that demonstrate to offer better quality, as the 1976 competition called ‘House 55’ to promote and encourage the improvement of industrialised housing (Noguchi et al., 2016b:342; Ryu, 1982:123).

In 1970, the Japanese government developed the ‘Parts for Housing Facilities and Standardisation’ research developed by the Japan Architecture Centre to push the construction industry to adopt ‘open systems’ and ensure that construction systems and components were compatible between each other (Ryu, 1982:121). Manufacturers of factory-made components were integrated into the supply chains of house manufacturers. As an example, the share of aluminium window sashes in new-built timber frame houses raised from 11% in 1965 to 88% in 1974. The open system and the increasing capacity of factory-made components manufacturers were engines that made mass customisation compatible in practice with mass production (Yashiro, 2014:21-24).

Accordingly, house manufacturers started changing their business models from an agency system to a direct sales system to improve their customer service; and thus, quality (Matsumura et al., 2018:8). The production volume of manufactured houses grew dramatically during the 1970s and 1980s. By 1970, 137,000 factory-built dwellings were sold, counting for 10% of the housing starts that year.

The privatisation of housing in the UK

In the 1960s, housebuilding production in the UK was more than double current production. Housing production got evenly distributed between the private and the public sector. Local authorities were producing council estates, while the private sector was developing land through low rise housing (Jefferys et al., 2014:4-7; Balchin, 1998:14-15).

Between 1963 and 1965, 85% of the Council's building were high-rise, produced using 138 different prefabricated panel systems for multi-storey housing manufactured by 163 different companies (Blanchet & Zhuravlyova, 2018:61-63). Industrialised construction systems were not exclusive to high-rise buildings. Local councils were using prefabricated components for most of their council estates, including mid-rise and low-rise housing. Even the private housing industry adopted some prefabrication systems for their housing developments (Ross, 2002:11). The following images are examples of projects built using prefabricated elements, including high-, mid- and low-rise housing typologies, produced by the council and private sector (Figs. 53 & 54).

 

Figure 53. (left) Park Hill estate in Sheffield, completed in 1961 (from Blanchet & Zhuravlyova, 2018:61– figure 5.1).
Figure 54. (right) Span Housing on Westrow (1959-61) private development by Eric Lyons & Partners (photo by Steve Cadam under Creative Commons Licence).

By the end of the 1960s, high-rise buildings suffer public criticism for being unsuitable for young families, expensive to maintain, quickly deteriorating and dangerous. Consequently, in 1967, the government withdrew the subsidy for building high-rise buildings.

In 1968, 'Ronan Point'—a tower block in East London assembled from prefabricated concrete panels— collapsed only two months after its opening. The Ronan Point disaster had a terrible impact on the social perception of prefabrication and multi-storey building. Consequently, the reputation of council housing and prefabrication systems decline and eventually lead the council to stop providing housing (Blanchet & Zhuravlyova, 2018:64-66; Turner, 2015:24). The following image shows Ronan Point partially collapsed in 1968 (Fig. 55).

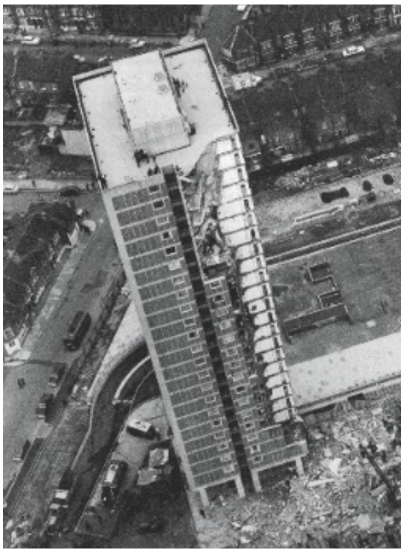

Figure 55. Ronan Point, East London, partially collapsed after an explosion in 1968 (from Blanchet & Zhuravlyova, 2018:65— Figure 5.4).

The private housing developing sector benefited by the decline of housing provision by the state because without the state providing houses, they gain control of the housing supply (Parvin et al., 2011:21). Since then, the housing supply in the UK has centred on the production made by speculative housing developers.

Housing developer's business model depends on speculative behaviour. Changes in governmental departments, policies and political parties have reinforced the position of the speculative sector as the primary house provider in the UK. Consequently, house prices have increased continuously, and housing completions reduced, because housing developers benefit on providing low supply in order to increase demand, and thus, house prices (Barlow et al., 2001:3; Parvin et al., 2011:42).

Government attempts to increase housing supply and moderate house prices have made the situation worse. The liberation of the mortgage market provoked a rise of demand and not of supply (House of Lords, 2016:18). In 1973, housing prices rose considerably, during the so-called 'Barber boom'[17], caused by an easing of credit conditions resulting in house-price inflation of 36%. Prices rose again by 16% in 1987 and 25% in 1988, caused by the implementation of the 'right to buy' policy. Policies as the 'Section 106 planning agreements' for affordable houses represent extra expenses to housebuilders, who need to restrain more supply to increase property prices; which accentuated by the economic crisis of 2008, resulted in a price inflation of 165% from 1997 to 2005 (Parvin et al., 2011:8; Wilson & Barton, 2019:9).

The leading housebuilders have absorbed smaller house providers to increase control over supply. In 1960, the ten most productive housebuilding companies contributed to 8-9% of total production, while in 2006, these accounted for almost half of new houses (Parvin et al., 2011:7).

The following graphic presents the housing production of new dwellings by local authorities, private market and housing associations from 1946 to 2013 with political shifts. It clearly shows how from 1945 to 1950, housing provision was centred on the provision of Prefabs by the government. Then, from 1950, the provision of housing was distributed between local authorities and the private sector, until the 1980s that local authorities stopped building houses (Elliot, 2014). Since then, housing supply has relied on the private market, where housing supply has decreased, and housing prices increased. Nowadays, the construction of new houses by local authorities is rising but still insignificant in relation to the private sector (Savage, 2018). The following graphic shows the distribution of housing starts in the UK (Fig. 56).

[17] The Barber boom refers to the measures in the UK budget that led to high inflation and wage demands from Public Sector workers between 1972 and 1973.

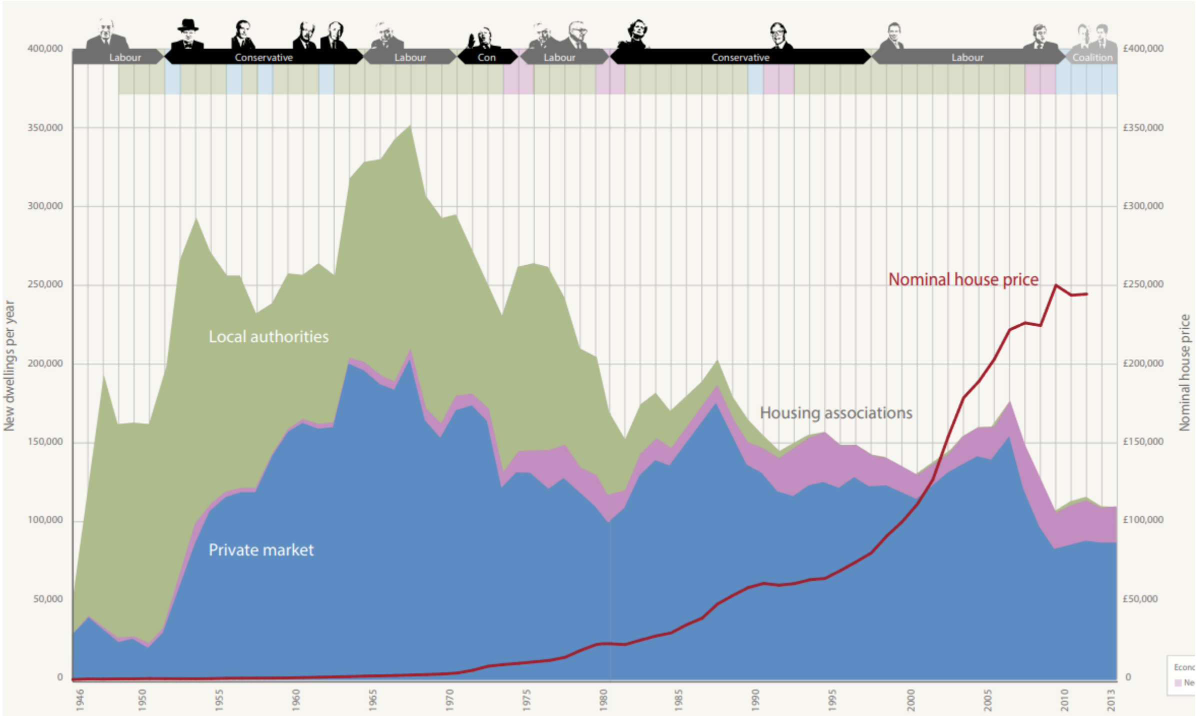

Figure 56. House starts in the UK by sector and related to Political context from 1946 to 2013 (Source: Jefferys et al., 2014:6-7; originally sourced from DCLG, Nationwide, HMT, Shelter analysis).

The restrictive and monopolised housing supply model present in the UK is causing:

- *Low productivity*— Housing supply does not meet demand. House completions in the last decade are the lowest since 1950 (Hall, 2011:72; Jefferys, 2014:4).

- *Low satisfaction levels*— 99% of new house owners have reported problems, where 26% count for more than 16 problems, causing that 10% of house buyers regret about buying a new house instead of an existing and 18% of them would not buy from the same supplier (HBF, 2019).

- *Lack of investment in R&D and innovation*— The level of investment in R&D in the UK housing sector is of only 0.1% of output (Farmer, 2016:35). Housebuilding limits to traditional construction systems (Hairstans & Sanna, 2017:225).

The Japanese bubble burst and decrease in land value

In the late 1980s and early 1990s, Japan experienced a radical estate price inflation driven by speculative behaviours known as the 'property bubble' era (Colombo, 2012). The housing bubble burst followed an economic crisis (Kobayashi, 2016:3). Residential land prices peaked in 1991 and then dropped from 1992 to 2005 (Kobayashi, 2016:7). Since 2005, land prices in Japan have been stable. The following graphic shows the volatile inflation and decline of land prices from the 1970s to the 2000s (Fig. 57).

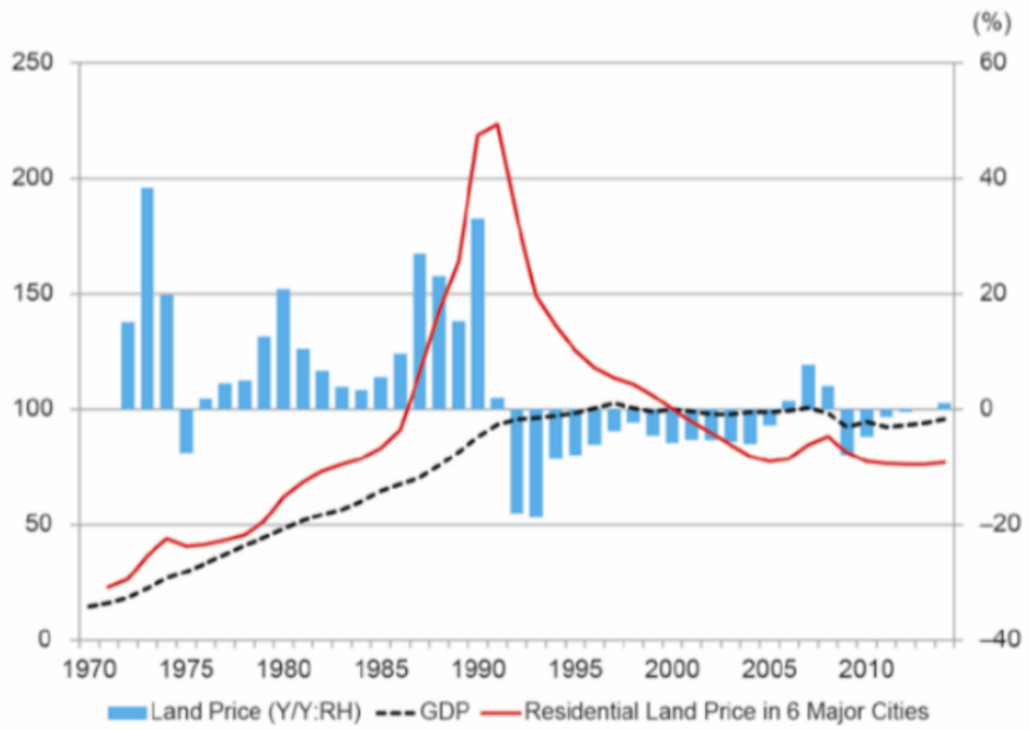

Figure 57. Land price and economy in Japan from the 1970s to the 2010s. (Source: Kobayashi, 2016:7; originally sourced: Japan Real Estate Institute; Government of Japan, Cabinet Office).

Since the bubble burst in 1992, land lost its value in the housing market. The business of house developers that followed speculative behaviours stopped being profitable.

Consequently, the Japanese government took actions to avoid the housing sector collapsing, providing incentives to housebuilders and adjusting legislation (Yoneda & Serweta, 2019). The policies introduced after the bubble burst focused on facilitating processes for the self-building sector to provoke the diversification of the housing market (Duncan, 1973:62; Johnson, 2007:20; Barlow & Ozaki, 2005:12; Noguchi et al. b, 2016:342).

House manufacturers are part of the self-built market. In Japan, self-build refers to the practice of a landowner of building in their land, using a contractor, architect or a house manufacturer. Thus, their business model centres on the production of houses, or as it can be said, on selling houses as products. The land is not part of their supply chain and cash flow.

Nowadays, the self-built sector in Japan counts for 75% of the housing market. The self-built sector benefits of rapid construction; thus, 90% of all single-family houses include prefabricated elements.

Locally based housing suppliers account for over 80% of the overall market and concentrate on smaller towns and rural areas. More than 90% of these firms supply fewer than ten dwellings annually. These independent housebuilders usually use a combination of pre-cut timber and traditional craft skills to build post-and-beam timber-frame housing (Barlow et al., 2003:138).

Factory-built house reached their highest production peak in 1994, counting for 18% of the total market. It currently accounts for 15% of the market[18], which is not only the highest percentage of factory-built houses by a single country but also the highest in volume. It counts for the production of 150,000 dwellings per year, which is around the same production of all houses in the UK (Johnson, 2007:11-20; Linner and Bock, 2013:160).

House manufacturers compete in the self-build market, where customer choice is prioritised (Barlow et al., 2003:135). Market share for prefabricated housing increases with costs, which corresponds to higher quality demand (Buntrock, 2017:194). In Japan, housebuilders opt for manufacturing construction systems to achieve higher quality and are able to sell their houses more expensive. The percentage of prefabricated houses in relation to the cost of the house increases with higher costs. For the top range of the Japanese housing market, prefabricated houses account for 49.8% of the market; while for the lower half ranges it accounts for less than 21%. The following graphic shows the percentage of prefabricated housing in relation to price range. It shows how the percentage of prefabrication increases with the price of the houses. The lowest price range presents an anomaly due it refers to mass produced housing and do not belong to the self-build sector (Fig. 58).

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[18] The 5% left is associated to self-made construction (without architectural or construction firm), community housing, housing for religious purposes and other type of housing types.

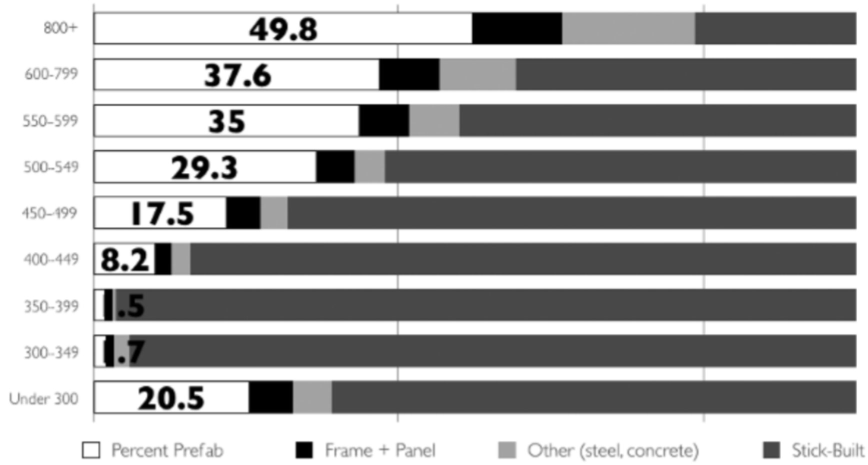


Figure 58. Percentage of prefabricated housing in relation to housing cost in Japan (Source: Buntrock, 2017:194—Figure 12.5).

Japanese housing manufacturers have pursued mass customisation strategies and are at the forefront of this approach. Japanese housing manufacturers are synonymous with premium housing and customer services. As an example, all house manufacturers offer warranties and service arrangements for long periods, often 25 years (Aitchison, 2018:94-95). The following graphic exemplifies the reasons that Japanese people consider essential for selecting a housing company, demonstrating high importance on reliability quality, performance and convincing selling process (Fig. 59).

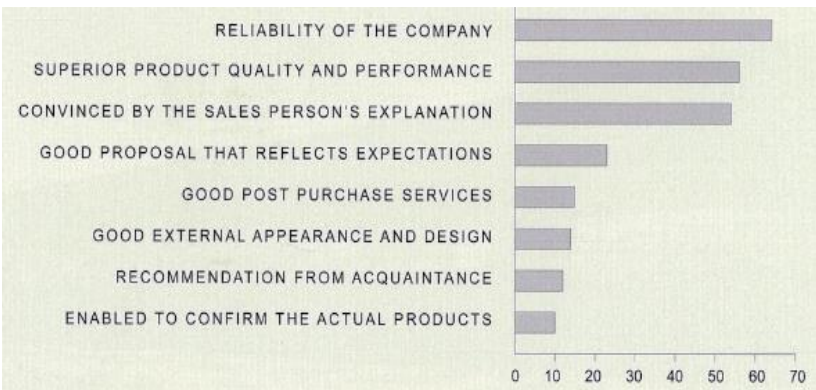


Figure 59. Buyer reasons for selecting Prefabricated companies in Japan in 2014 (from Aitchison, 2018:95; originally sourced from the Japanese Prefabricated Construction Suppliers and Manufacturers Association 2014 survey).

Reliability of housebuilders, identification of brand associated with quality, customer-oriented service and customer satisfaction, are attributes related to the Japanese factory-built sector that are not present in the UK housing market (Barlow et al., 2003:143). In the UK, there is dissatisfaction on the part of consumers and government over the industry's performance, especially in terms of its ability to meet volume and quality standards expected of modern industry (Naim & Barlow, 2003:600).

The Land effect on the housing process

In the UK, 90% of the new houses are built through processes of land speculation, while in Japan only 25%. The specific conditions of the UK have turned land speculation into a reliable and highly profitable business (Ball, 2003:908–909; DCLG, 2017:13; McKibbin, 2018).

Japan land limitations

In Japan, land available for development is minimal. The Japanese territory is slightly larger than in the UK, but it contains almost double of population. Japan has 380,000 people per square kilometre.

Land available for urban development is limited to flat areas as it is dangerous to build on slopes due to seismic conditions (Sassa et al., 2004). 73% of the country is mountainous meaning that only 30% is suitable for agriculture or urban use (Martini & Kimura, 2009:25). Consequently, 66% of the country counts for forestry, 5% for wild field and water surface and only 13% for agriculture land, leaving only 5% of the territory for urban settlement (Hiroyuki, 2018). The following image shows the distribution of land use in Japan (Fig. 60).

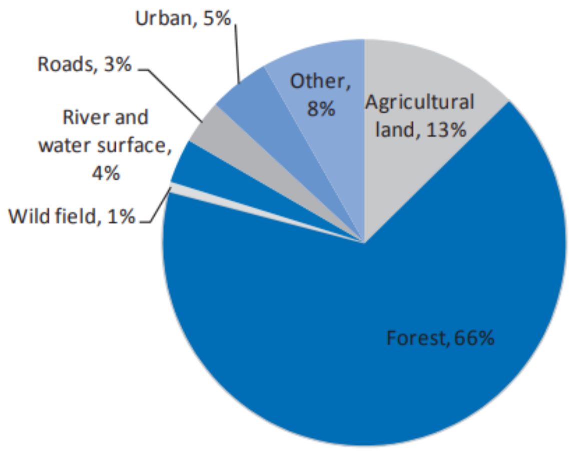


Figure 60. Land use distribution in Japan (Martini & Kimura, 2009:25; sourced initially from the Annual Report on Land, Ministry of Land, Infrastructure and Transportation).

Agriculture land has been losing value for 23 straight years. However, it is protected by the government to avoid turning into urban areas (Martini & Kimura, 2009:11,35). Therefore, land availability in Japan is low.

Consequently, the Japanese population is highly concentrated. The Tokyo-Kanto metropolitan area homes 29% of the entire population, and 92% of the population lives in cities. Japan has three metropolitan areas, with over ten million population.

In contrast, the UK largest city– Greater London– has nine million population and is home to 13% of the UK population. None of the other urban centres exceeds three million population. The urban density is usually higher in Japanese cities than in the UK. For example, Tokyo's density is around 6,000 people per square kilometre while in London is of 4,500. The UK population is distributed more evenly in its territory than in Japan. 83% of its population lives in cities.

UK land availability and control

Under 20% of the territory in the UK accounts for mountainous areas. Forestry regions in the UK count only for 11%. Urban areas are 5-7% and agricultural land 76% of the territory.

The UK possesses a housing deficit of 250,000 dwellings per year. The UK's housing shortage is not a matter of land availability, as there is a current stock of 500,000 unbuilt plots with planning permission, which is higher than the present housing demand (Griffith & Jefferys, 2013:13; Jefferys et al., 2014:4; Jefferys, 2016).

In the UK, the land is restricted because housing developers hold stocks of land without developing them. They adjust planning permission and construction in response to economic cycles that allow them to maintain and increase the value of the land they own, a process known as land-banking (Ball, 1983:143). Housing developers invest heavily in the acquisition of large portions of land and bank these for several years until the most profit extracted from its selling (Parvin et al., 2011:24). The following table presents the investment of land of housing developers in the UK (Table 8).

Table 8. Housing developers' investment on land in the UK; Barratt, Persimmon and Taylor Wimpey examples (Sourced from the 2017 financial full reports of each company).

UNITED KINGDOM		Housebuilders / Housing developers		
		Barratt	**Persimmon plc**	**Taylor Wimpey**
	Homes completed in 2015	16,647	16,043	13,341
Finance (£M)	Turnover / Revenue	£4,650	£3,422	£3,965
	Operating profits	£799	£966	£841
	Net Income	£616	£787	
	Net Cash	£724	£1,302	£511
Land	TOTAL Number of plots (land)	80,752	98,445	192,094
	Acres held (2017)	11,737	16,100	-
	Number of Plots in 'short-term landbank'	70,523	54,300	76,000
	Plots anticipated from 'strategic land holdings'	71,600	100,000	107,000
	Number of land approvals (per year)	18,497	17,301	-
	Land bank years (average)	4	6	6
	Land cash spend (annually)	£ 1 bn	£ 602 M	-

This table reveals the importance of land for housing developers and the high control they have over it. The number of houses they build is significantly low compared to the number of plots they own. Barratt builds only on 20% of the plots they own, Persimmon plc 16% and Taylor Wimpey 6.9%. They bank the land for four and six years respectively. Therefore, different from Japan, land in the UK is not developed because it is controlled by housing developers not because there is no land availability.

Negative aspects of land speculation

The success of housing developers in the UK relies on their ability to buy land at low prices and reduce construction costs as much as possible. Once the housing developers buy land, they carry a series of risks, such as planning delays, construction problems, interest rate changes and house price variation. Bringing land into the housing system means prioritising land acquisition over construction quality and provision of affordable housing and infrastructure provision (Ball, 1983:167; Parvin et al., 2011: 8; Jefferys et al., 2014:32-34).

Land speculators' profit depends on the ultimate value of the properties. However, unlike other markets, the price that properties fetch is determined by the real estate market, which includes existing houses (Naim & Barlow, 2003:600). Thus, the price of the property is fixed by the market, while the cost of land and construction are variables. The lower the cost of land and construction costs are, the higher the profit.

Housing developers keep supply scarce to keep demand high; and thus, provoke low buyers' concern about quality and price. Technical innovations, such as prefabrication, are applied not to increase quality or reduce the selling price, or as Parvin et al. (2011:26) refers to as *'providing the same for less, [instead than] providing more for less'*.

Land speculation system benefits companies with access to significant funds as this allows them to buy more land and hold it for longer. Small and medium housebuilders find it hard to compete (Jefferys et al., 2014:9). The following diagram shows the point where speculative housebuilders compete and how it is centred on land assets (Fig. 61).

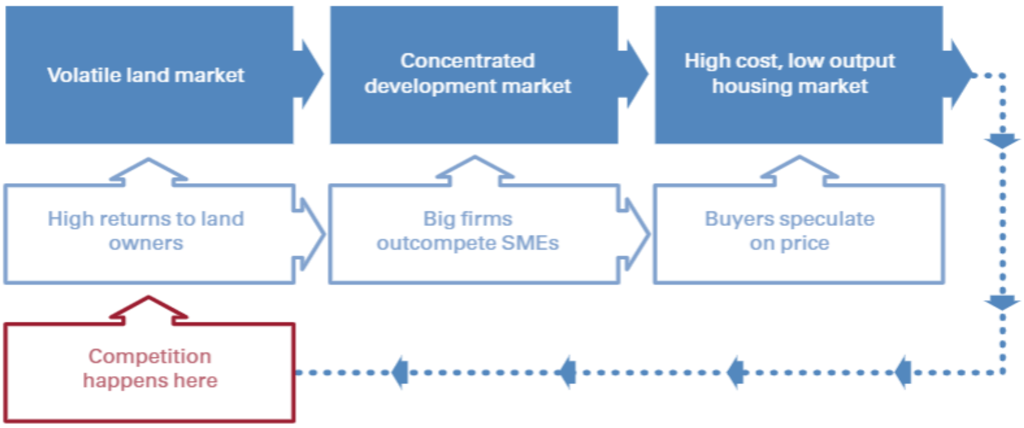


Figure 61. Housing steps emphasising where land speculation competes. SME— small and medium enterprises (from Jefferys et al., 2014:9).

In Japan, land supply and demand run to a different model. The land is scarce, and its value does not increase with time; therefore, land speculation does not guarantee profitability. Housebuilders cannot control housing supply to increase demand; therefore, they need to compete in quality, customer satisfaction, performance, 'green' features, style, branding or marketing (Yamada, 1999:109; Barlow and Ozaki, 2005:18; Johnson, 2007:41). The following diagram explains where Japanese housebuilders compete and how that affects the housing market (Fig. 62).

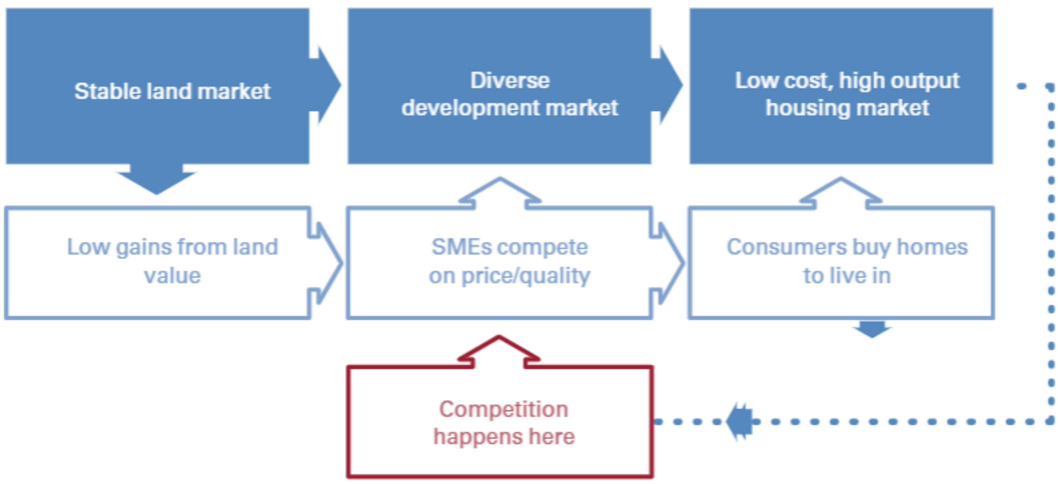


Figure 62. Housing steps emphasising where housebuilders compete without land speculation. SME— small and medium enterprises (from Jefferys et al., 2014:11).

Housing prices

In the UK, housing prices have been rising since the Second World War with severe instability in recent years. In contrast, Japanese housing has been stable since 2005 (Muellbauer & Murata, 2009:26; Colombo, 2012). In perspective, the average price of a house in the UK in 1971 was of £5,362, less than 3% of today's average price of over £200,000 (Jefferys et al., 2014:32). The graphic below shows the different house price index between Japan and the UK (Fig. 63).

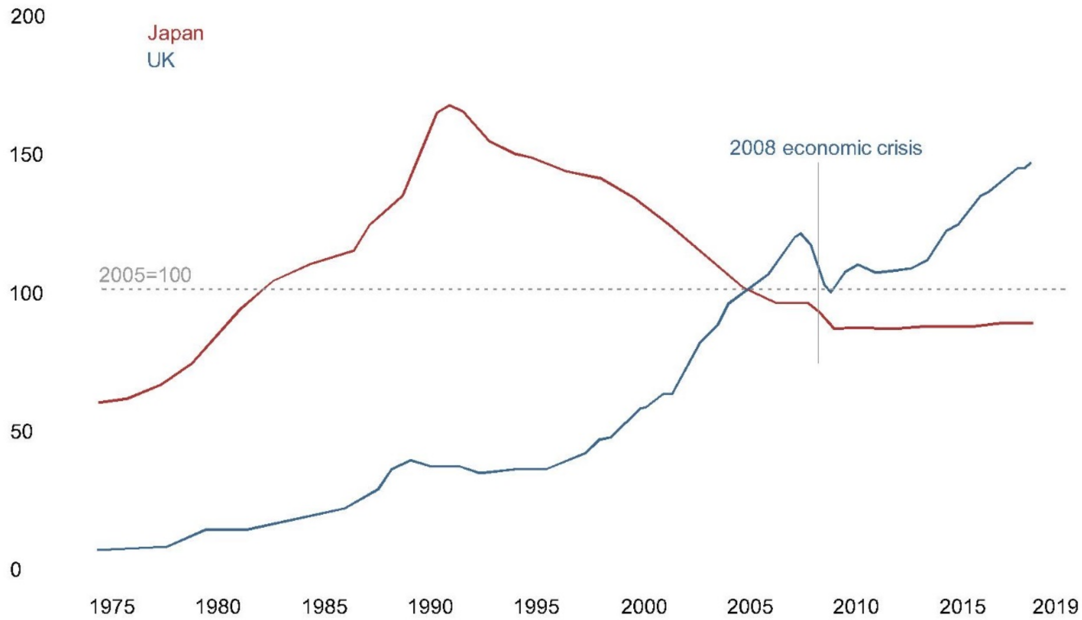


Figure 63. Japan and UK property price index considering 2005=100 (Diagram by the Author with information from Grunebaum, 2019)

The graphic above also shows how the property prices of Japan reach a historic peak in 1992 and then collapsing until 2005. Speculative behaviours in housing caused the radical price rise and drop presented in Japan during the 1990s (Harding, 2016).

Nowadays, the average property in the UK costs £226,000, while in Japan they cost £240,000 (¥35,760,000) (HM Land Registry, 2019; Heath, 2019; Real Estate, 2016).

Housing price comparison is attached to the location. As an example, properties in London are more expensive than in Tokyo for over 60%. Comparing price inflation is more significant than the prices themselves. The following graphic shows the price increase in relation to the population growth of London and Tokyo, where London prices are highly increasing, and Tokyo are stable, despite that, both cities have a similar population growth rate (Fig 64).

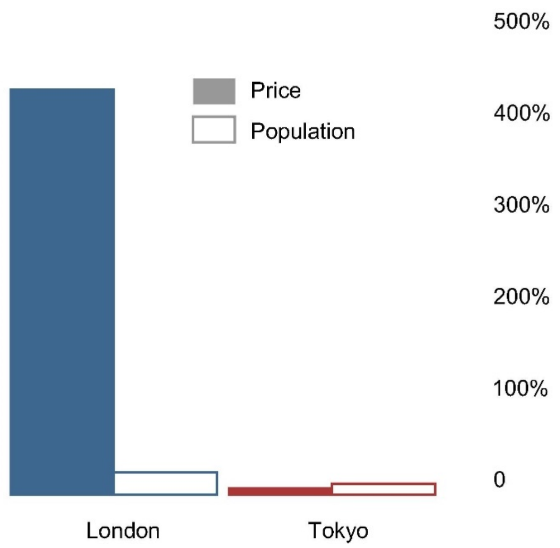


Figure 64. Change in house price and population, 1995-2015 (diagram by the author with information from Harding, 2016)

The London vs Tokyo scenario is a clear example of how prices are rapidly rising in the UK while stabilised in Japan in the last decades.

In the UK, buying a house is also connected to tradition and investment purposes. The buying process involves precise timing and research about the location's value. Economic interests of investment and payback times are central factors in the purchasing decision making.

In Japan, buying a house is a lower risk decision as properties' value do not increase, and locations are already determined. Timings and investing factors do not determine purchasing decisions. Quality, resistance against disasters and suitability to the buyer's wants and needs are the main factors in the buying decision-making process (Kobayashi, 2016:30; Harding, 2016).

There is a current discourse emphasising the importance of modifying legislation and the planning system to increase land supply and housebuilding in the UK. It has been stressed that supporting self-building could help to increase housing supply, and thus, stabilise house prices and increase housing quality (Pravin et al., 2011:34-35, Jefferys et al., 2014:18-23; Brown et al., 2013:36-39; Barlow et al., 2001:32-34; Wallace et al., 2013:49-64).

Legislation and planning

Laissez-faire legislation in Japan

In Japan, legislation and the planning system empower landowners with the freedom to build anywhere, mainly if it is for residential purposes. Japanese legislation protects landowners to build with very low restrictions and simple planning processes. Japan's constitution declares that 'the right to own or to hold property is inviolable' (Harding, 2016). As a result, landowners can build in any shape and style, only controlled by allowable floor ratio and height concerning roads and adjacent buildings.

The Japanese *laissez-faire* legislation is a consequence of political interventions created after the bubble burst in 1992 to keep housing production high and save the housing industry. The planning system was redesigned to avoid housing inflation and keep the construction industry production high by stripping municipalities of the ability to control private property development (Beyer, 2016). The construction industry adjusts to the legislation to suit housing owners.

Japanese planning is regulated by twelve zones, which are stipulated by the government and planning agencies as areas in the city (City Planning Division, 2003). The zoning areas work as restriction areas for the construction of certain buildings types. Nuisance levels define the zones. Houses, considered of low nuisance level, are allowed in most of the zones, but the industry does not (Breach, 2019). The following image shows the different zones in Japan and describes what is allowed in each of them (Fig.65)

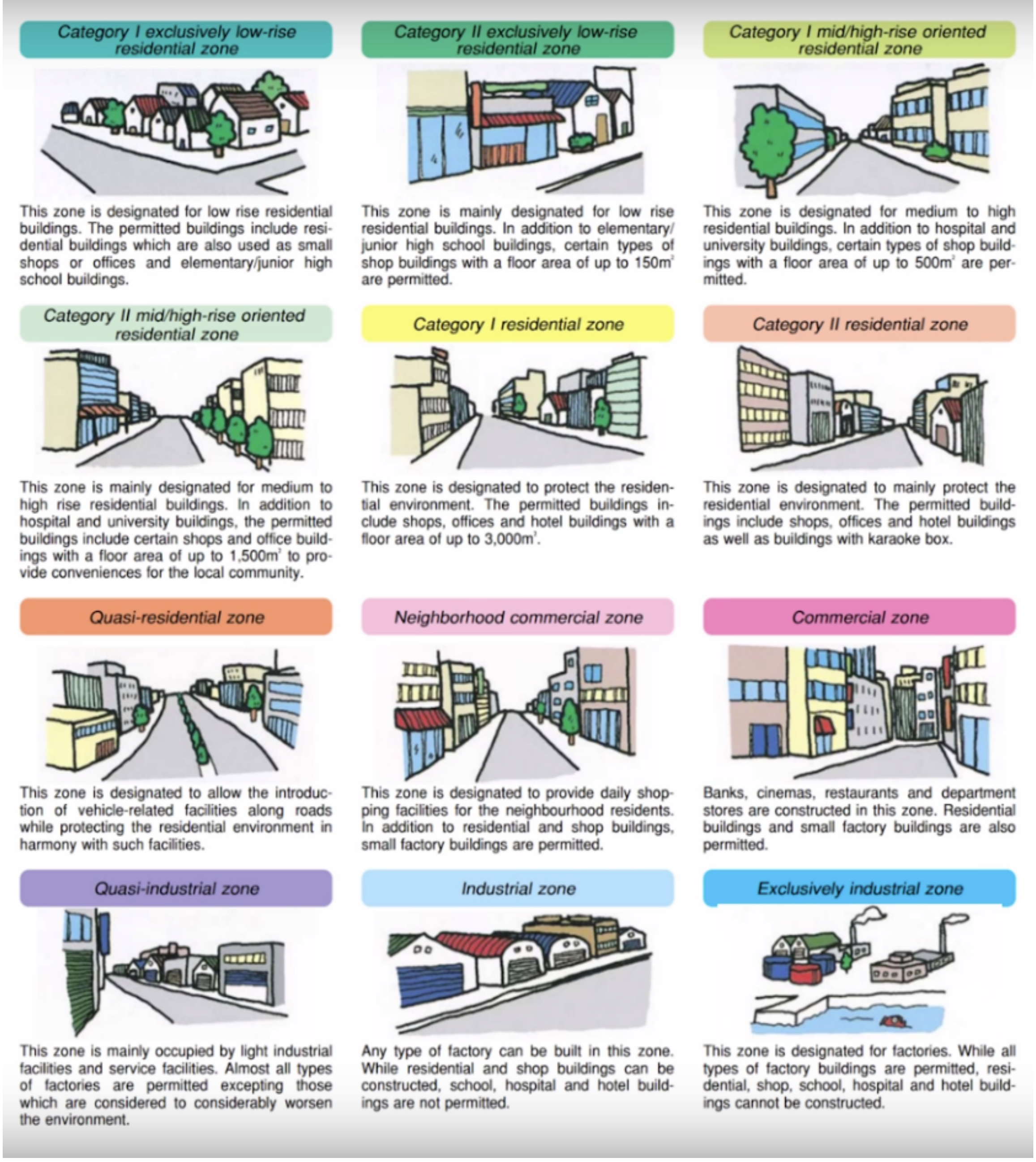
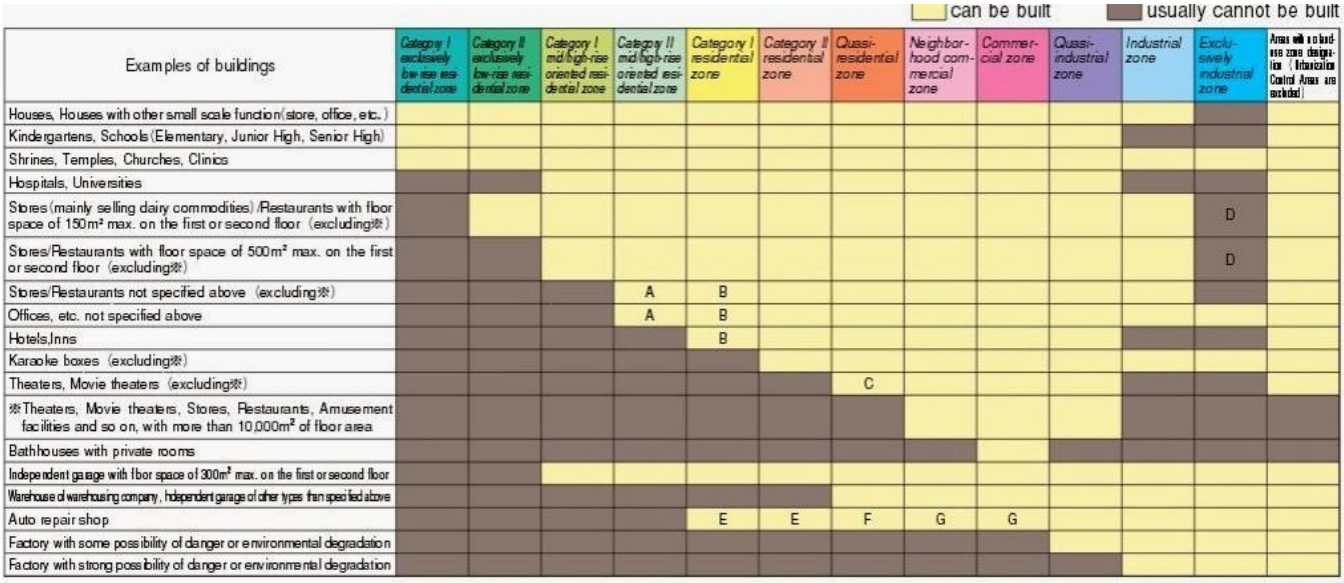


Figure 65. Land use zones in Japan. (Source: City Planning Division, 2003).

Therefore, in Japan, it is possible to construct houses or convert buildings to houses almost everywhere. Zoning does not apply to them, except for the exclusively industrial zone (Harding, 2016). The following chart shows the flexibility of the zones systems for specific building types, including dwellings (Fig. 66).



Examples of buildings	Category I exclusively low-rise residential zone	Category II exclusively low-rise residential zone	Category I mid/high-rise oriented residential zone	Category II mid/high-rise oriented residential zone	Category I residential zone	Category II residential zone	Quasi-residential zone	Neighborhood commercial zone	Commercial zone	Quasi-industrial zone	Industrial zone	Exclusively industrial zone	Areas with no land-use zone designation (Urbanization Control Areas are excluded)
Houses, Houses with other small scale function(store, office, etc.)													
Kindergartens, Schools (Elementary, Junior High, Senior High)													
Shrines, Temples, Churches, Clinics													
Hospitals, Universities													
Stores (mainly selling dairy commodities) /Restaurants with floor space of 150m² max. on the first or second floor (excluding※)												D	
Stores/Restaurants with floor space of 500m² max. on the first or second floor (excluding※)												D	
Stores/Restaurants not specified above (excluding※)				A	B								
Offices, etc. not specified above				A	B								
Hotels,Inns					B								
Karaoke boxes (excluding※)													
Theaters, Movie theaters (excluding※)							C						
※Theaters, Movie theaters, Stores, Restaurants, Amusement facilities and so on, with more than 10,000m² of floor area													
Bathhouses with private rooms													
Independent garage with floor space of 300m² max. on the first or second floor													
Warehouse of warehousing company, Independent garage of other types than specified above													
Auto repair shop					E	E	F	G	G				
Factory with some possibility of danger or environmental degradation													
Factory with strong possibility of danger or environmental degradation													

Figure 66. Control of building use by land zone (Source: City Planning Division, 2003).

Detached housing in Japan

In Japan, construction regulations demand a physical gap between buildings to protect them against earthquakes and fire. Detached houses are the main form of housing in Japan, even in dense cities like Tokyo (Ozaki & Lewis, 2006:100). The legislation also allows the easy subdivision of land. Plots in housing areas are usually compact and account for detached houses. Consequently, self-building is a common practice even in very dense cities. The following image shows the urban fabric of a neighbourhood in Tokyo as an example of single-detached houses inside dense urban areas (Fig. 67).

Figure 67. Kiyonori Kikutake's Sky House, Tokyo; single-detached houses (from Koolhaas & Ulrich, 2011:159).

Controlled planning system by planning authorities in the UK

In the UK, the planning system is designed to provide control to local councils over landowners. Dwelling form, shape, style and zoning must be consistent with legislation and existing housing stock. Thus, innovative dwelling proposals suffer from long and complicated planning processes (Butterworth & Baker, 2018).[19]

The UK does not use zoning as a planning technique. Planning permission is given by the planning committees following internal protocols and decided on their criteria (Wetzl, 2018). The UK uses a 'Class Order' to categorise land usage into groups. Planning permission is given, which are categorised into four groups. 'Class A' covers shops and other retail premises such as banks and restaurants, 'Class B' includes workshops, factories and warehouses, 'Class C' are residential uses and 'Class D' are non-residential institutions, assembly and recreational uses. Each class includes subclasses that define uses in higher specificity (Planning Jungle Limited, 2019). Among all the subclasses of Class C, the construction of houses is limited to only two subclasses (Class C3 and C4). The following diagram shows the different land classes present in the UK (Fig. 68).

[19] The Author developed a conference paper focused on analysing the planning application system from the perspective of a housing entrepreneur in Scotland. The paper is named 'Barriers to Innovative Housing in Scotland: NRGStyle's 'ZEMCH 109' Case Study' and is attached as an appendix to this thesis.

Figure 68. Residential land classes in the UK (from Nelson, 2016).

The categorisation of classes is strict. Class C3— for dwelling houses— covers use by a single person or a family, an employer and domestic employees and the person receiving the care and a foster parent and foster child, but only up to six people living together as a single household. Classes are tagged to properties and not to the land; therefore, in the same piece of land, there could be a flat C3 and a business A4, for example. Properties can change class, but these changes are under consideration of the authorities and need to obey the planning order.

Consequences of each planning system

In Japan, the *laissez-faire* legislation and planning system centred on landowners benefit the self-build sector over the speculative. Consequently, different housing business models to coexist, generating a diverse and open housing market focused on dwelling rather than controlling the land (Beyer, 2016; Sunikka-Blank & Iwafune, 2011:357; Harding, 2016; Smith, 2018). Consequently, housebuilders compete in quality and service.

In Japan, the housebuilding industry is larger than the UK and dominated by self-builders (Parvin et al., 2011:35). House manufacturers offer exclusive technology dependant to industrialised processes, like anti-seismic technology and integral inclusion of amenities and renewables (Noguchi, 2003:360,362-363; Breach, 2019).

In the UK, legislation and planning systems provide control to planning authorities, causing self-builders to struggle to offer a practical and highly customised service.

House developers and self-builders do not compete in the same market. Thus, housing developers see customisation and quality in construction as costs rather a selling point, as there is no market competition (Barlow et al., 2001:44). Housebuilders in the UK have cited building and planning regulations as barriers to increased customisation (Naim & Barlow, 2003:600).

Housing need

Supply and demand

It is estimated that the UK needs 400,000 new houses per year; however, the housing industry only supplies 150,000. Consequently, the UK has a housing deficit of 250,000 houses per year, a deficit which has increased by 50% in the last ten years (Wilson & Barton, 2018:3,8; Brown et al., 2013:4; House of Lords, 2016:3,4,16). Housing need is not only a matter of supply and demand. Housing need refers to the characteristics of the housing needed by the population, including cost, location and type (Hewes, 2017).

Japan overcame his housing deficit in the 1970s; since then, their housing supply and demand have been balanced (Knoroz, 2017:25-29). The Japanese housing industry supplies over 950,000 every year. However, by 2003, there were 25,000 people in a homeless situation, despite having an abundant housing supply.

The housing need relates to the capacity of the housing industry to supply by the socio-economic conditions of each context. The following table shows a socioeconomic comparison of Japan and the UK (Table. 9)

Table 9. General Socio-economic comparison— data range from 2017-2019 (Sources: Countryeconomy; Projectbritan; and Trading economics).

	Japan	**UK**
Population (M)	127	66
GDP (M$)	4,971,900	2,828,600
GDP per capita ($)	39,200	42,700
Form of government	Constitutional monarchy	Constitutional monarchy
Debt (M$)	11,400	2,500
Debt (%GDP)	235%	87%
Exports % GDP	14%	17%
Imports % GDP	14%	24%
Total land area (sq. km)	377,837	244,110
Density (people per sq. km)	335	272
Unemployment rate	2.3%	3.9%
Average wage ($)	41,350	55,050

Housing starts

The Japanese build significantly more houses than the UK, with 970,000 compared to 152,000 in the UK. The UK housing starts are low, not only in comparison to Japan but against other countries in Europe. The Japanese housing starts are high compared, not only to the UK but compared to other countries. To put this into perspective, Japan has comparable housing starts to the US, with only 40% of the population (Yoneda & Serweta, 2019). The following graphics show a comparison of housing starts and relates to Japan and the UK with other countries to provide a sense of perspective, showing how the UK has been historically stable between 150,000 and 400,000, while Japan housing starts have risen over 1,800,000. (Figs. 69 & 70).

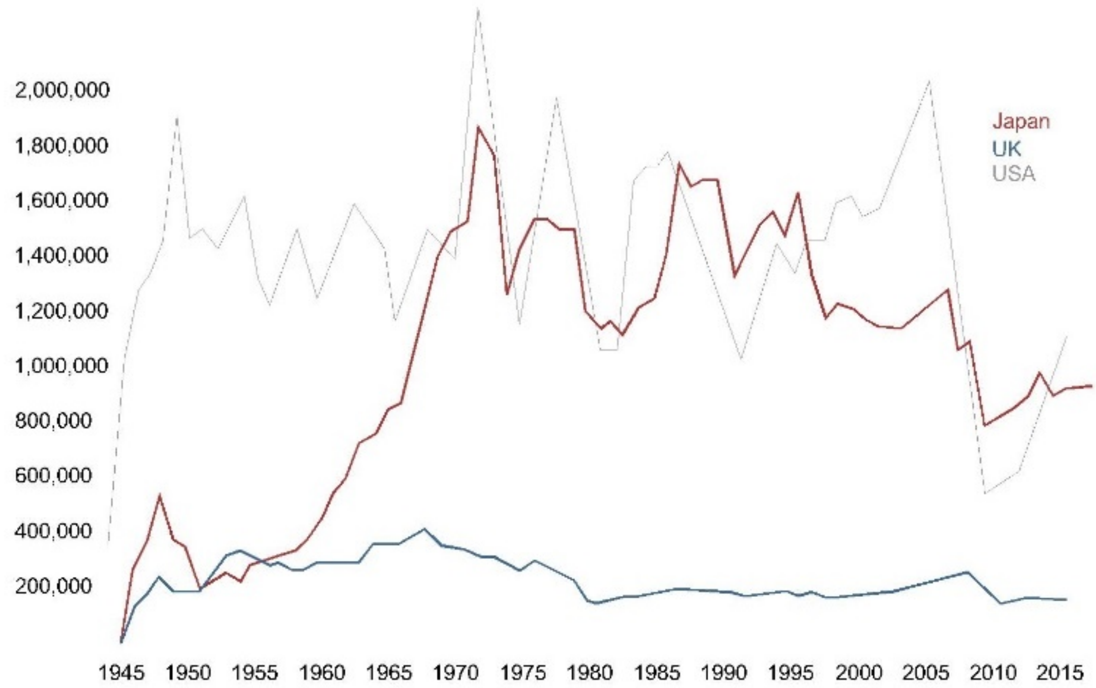


Figure 69. Number of Housing Starts in Japan, the US and the UK from 1945 to 2015. For USA, the first housing peak relates to housing programmes for 'homecoming' soldiers from the Second World War, similar to Japan and the UK. The drastic peaks of the 1970s are related to the 'Great Inflation'. The peak and drop reflected at the end of 2006 relates to the 'housing bubble burst' prior to the 2008's economic crisis (Diagram by author).

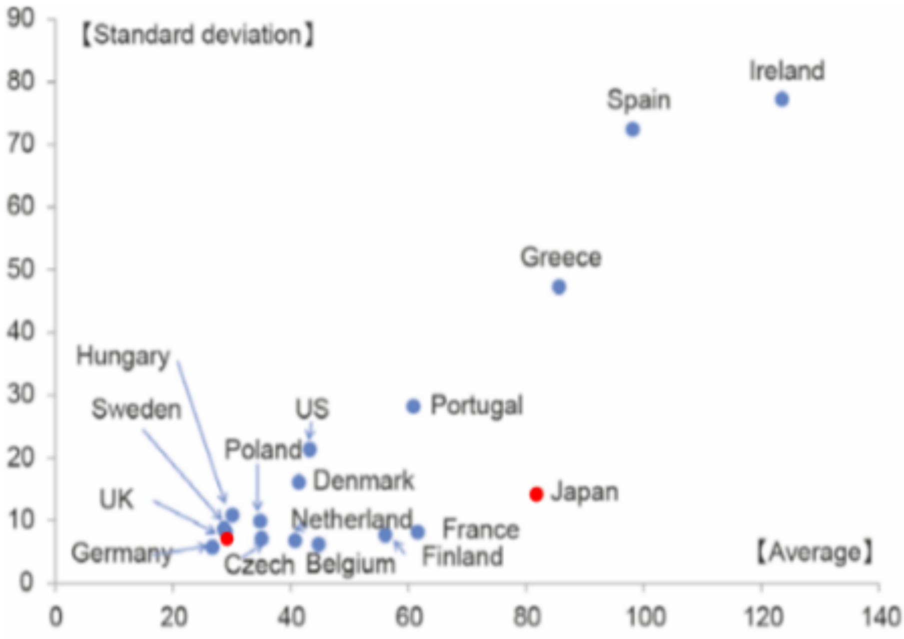


Figure 70. Housing starts per 10,000 capita from 2002-2013. (from Kobayashi, 2016:14— Figure 16; originally sourced from EMF Hypostat 2014; Eurostat; Ministry of Internal Affairs and Communications; Ministry of Land, Infrastructure, Transport and Tourism; National Institute of Statistics and Economic Studies (France); US Department of Commerce.)

As observed, both countries have a reasonably stable housing production despite being opposite in the number of housing starts. Japan is among the four countries with more housing starts in the last years, being the most stable among them (Kobayashi, 2016:14). In contrast, the UK has a very low housing starts with a very stable ratio.

Japan is building six times more new houses than the UK with only twice its population and building four times more houses per capita than the UK (Harding, 2016) (Fig. 71).

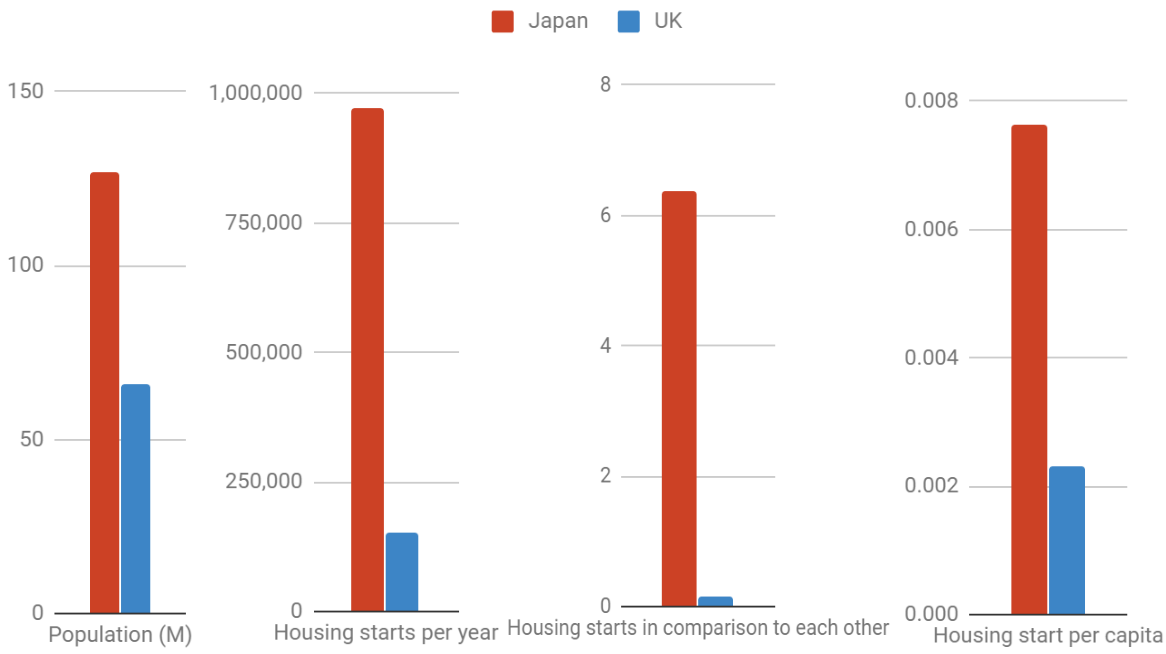


Figure 71. Comparative housing starts between Japan and the UK in relation to population (by the Author).

Population growth and ageing, and dwelling ownership

In Japan, the housing starts ratio has acted in accordance to their population and economic growth; rising from the 1950s to the end of the 20th century, stabilising and started to decline slightly in the last years. However, the housing starts in the UK have not followed the same pattern. In the last years, the housing starts in the UK have been the lowest since the end of the Second World War despite having an increasing economic and population growth (Parvin et al., 2011:11). The following image shows the population growth from 1950 to the present days and its projection to 2040 in relation to the economic growth of Japan and the UK (Fig. 72).

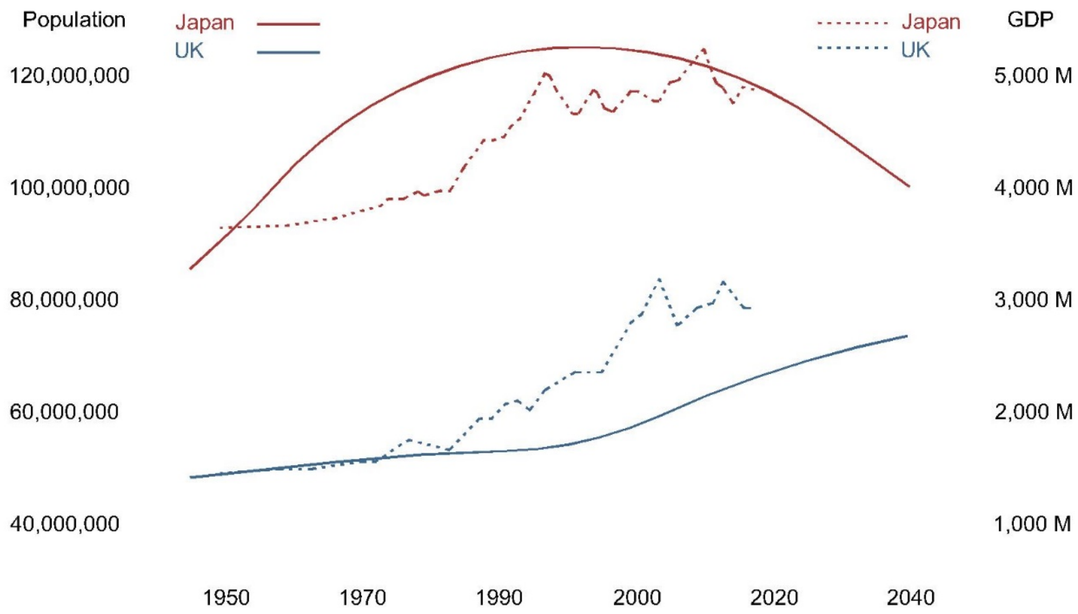


Figure 72. Population growth and prediction in Japan from 1950 to 2040 in relation to GDP growth in Japan and the UK from 1950 to 2019 (Diagram by the author; data sourced from data360.org; sourced initially from U.S. Census Bureau, International Data Base; tradingeconomics).

Population in Japan is declining by 0.3% annually. Japan possess low levels of immigration and changes in social behaviours that are reducing the birth rates. The marriage and partnership rates are reducing, modern families have less children, and the 'baby boom'[20] generation is ageing (Soble, 2017a; Semuels, 2017). Japan is the population with the highest ageing population, with 27% of its population aged over 65 years old. The UK population is also ageing; 19% of its population is over 65 years old, which means that the UK is the 23rd country with the highest ageing of the population. It is calculated that the population over 65 years old will account for 30% in 2066 (Storey, 2018:2; Kamm, 2018).

Ageing population affects the housing distribution, type of housing and ownership. Economic crisis and uneven wealth distribution are causing that young people cannot

[20] The term baby boom refers to the increase in births after the end of the Second World War.

afford houses. The following image presents the UK ownership rate categorised in age sectors (Fig. 73).

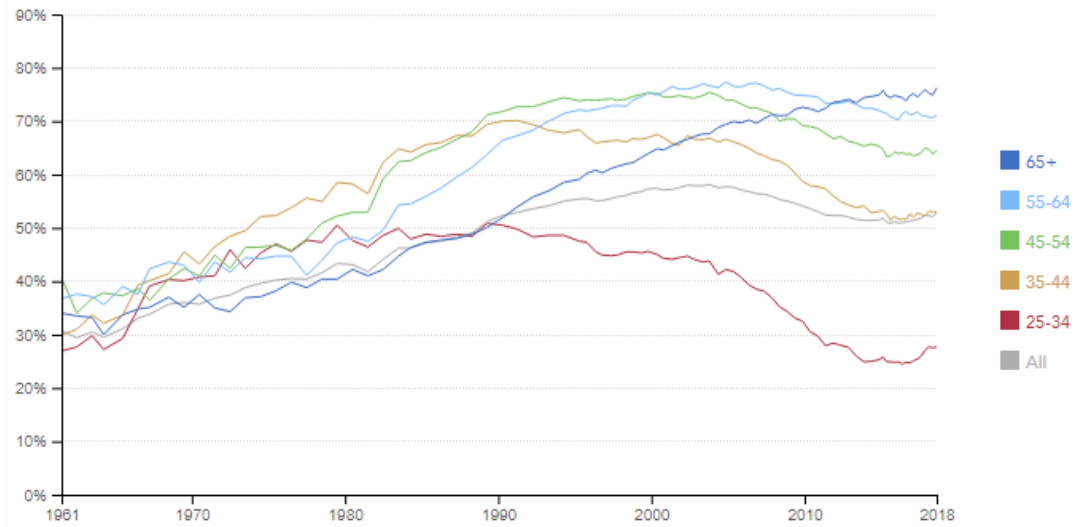


Figure 73. House ownership rate in the UK. Notes: There is a change of data source in 1984, resulting in small inconsistencies. Before 1980, housing association renters are included in the private rented sector. Before 1984, full-time students in parents' homes are included as single adults in parents' homes. 'All' includes families under 25. (Source: Resolution Foundation, 2019)

Dwelling ownership in Japan counts for 60%, while in the UK counts for 68%. Ownership rate in the UK is rising, while in Japan, it is stable (Kobayashi, 2016:8).

Japan's interest in technology and industrialisation is a strategy to cope with the lack of workforce caused by an ageing population (Klein, 2017; Minami, 2016:672). Japanese industrialisation and use of high cost-performance also relate to their tradition of industrial investment, and constant updating of the housing market wants and needs (Noguchi, 2013b:167-169; Pernice, 2007:238-239). Manufacturing industry benefits from high and constant sales. The Japanese housing manufacturing sector is heavily industrialised as it has been reliant to economies of scale (Bock & Linner, 2015:93-98).

However, population shrinking, ageing and economy decrease are affecting the housing industry in Japan. Misawa Homes was restructured between 2003 and 2006 to face a half a billion dollars in debt. Toyota purchased stakes in Misawa and now share a single R&D department. House manufacturers are closing production plants to increase their efficiency. House manufacturers are making their customisation processes more effective to keep providing high customisation while reducing production variability. Production lines are cut down as the only strategy to generate savings in the already highly automated production systems. Sekisui House, for example, offered 110 models in 1997, but only 50 three years later (Buntrock, 2017:203).

Housing production in Japan remains high despite the shrinking of the population. Housing manufacturers still have high housing production levels because the housing market in Japan is on constant reconstruction and dwellings have a short lifespan.

Short dwelling life in Japan

The average age of houses in Japan is estimated to be around thirty years (Kobayashi, 2016:27; Brasor & Tsubuku, 2014). Japanese houses have a short lifespan, particularly compared to the UK where houses last at least twice than the Japanese average.

Japanese houses have such short lifespan, mainly because of constant exposure to natural disasters (Kuma, 2016:27; Morris, 2017). During the Great East Japan Earthquake in 2011, 300,000 buildings were destroyed (double of the total production of houses in the UK in one year) and over 1 million damage.

Earthquakes and tsunamis— which eventually lead to fire— not only cause the direct destruction of housing stock but provoke the reconstruction of the built environment and implementation of new construction legislation in search of improving the buildings' endurance (Brasor & Tsubuku, 2014; Smith, 2018; Harvard Map Collection, 2017).

Another phenomenon that affects the longevity of houses is how properties and houses are valued. In Japan, houses are valued separately from the land, which encourages people to rebuild when their houses are valued less than the land to bring value back to their properties (Barlow & Ozaki, 2001:7; Barlow & Ozaki, 2005:18; Noguchi, 1994:11-13). The present-day, the land price in Japan is stable, but the houses tend to depreciate, which accent on the rebuilding process and decreases the dwelling's lifespan, caused by a cultural preference for new houses.

Japanese investment in property follows different values than the UK. Properties are not valued as an economic asset because the land is not gaining any value with time. In Japan, ownership is related to the desire for a better quality of life and freedom (Flanagan, 2017; Tiwari, 2000:88-89; Lam, 2017).

Japanese preference for new houses

The robust demand for new houses in Japan can be attributed to their constant tearing down and replacing of housing, a phenomenon known as ‘scrap and build’ (Berg, 2017; Morris, 2017; Kobayashi, 2016:27; Klein, 2017). In 2014, Tokyo itself had around 142,000 housing starts compared to the 137,000 houses started in the entire country of England— where Tokyo has a population of 9 million against 55 of England (Beyer, 2016).

The scarp and build culture is rooted to the low-quality housing procurements used after the Second World War, a cycle of poor maintenance of houses and continuous legislation revisions to improve earthquake resilience (Berg, 2017). In Japan, a twenty-five-year-old house is already considered old (Tsukamoto & Almazán, 2006:8; Morris, 2017).

Today, the Japanese dwellings’ lifespan is particularly short because in 1981, the government changed building regulations. The government set a new structural standard to avoid the urban damage presented in the Miyagi Earthquake of 1978. Consequently, buildings constructed before 1981 have a low value and tend to be demolished (Brasor & Tsubuku, 2014; Braw, 2014). In the ‘1995 Hanshin Earthquake, only 0.3% of post-1981 buildings *(shin-Taishan)* suffered severe damage, while 8.4% of the buildings constructed pre-1981 standards (*kyu-Taishan)* were severely damaged (Sekisui House, 2018:12).

In Japan, resistance to natural disasters is equal to building quality. It has been explicitly expressed that '*"high-quality" mainly means "won't fall down in an earthquake"'* (Harding, 2016; Sekisui House, 2017:2). Consequently, house manufacturers are promoting that their houses are very resistant to earthquakes and that they will last three times longer than the current dwelling lifespan (DaiwaHouse, 2017:35,65,67; Sekisui House 2018:41-46).

This marketing strategy is part of a cultural association of housing as a 'disposable commodity', also linked to a strong attraction to new technologies. In Japan, the technological shift cycles are rapid. New houses are equipped with improved technologies— like double/triple glazing, sophisticated toilets and baths, interactive monitoring systems and tile-shaped solar panels, among multiple other features— that make them very attractive at comparable prices (Noguchi, 2013b:164-172; Lam, 2018).

The Shinto religion might also influence the scrap and build culture as the demolishing and rebuilding of buildings is part of their customs and traditions (Isozaki, 2006:126; Sand, 2015:126, 151-152; Lam, 2017).

Japanese people also find it preferable to buy a new house than an old house because mortgage interest rates are low, and warranties are better for new houses as these comply with updated standards. Moreover, new houses are better maintained and have technological advantages that drive most people to opt for them (Lam, 2017; Lam, 2018).

The lifespan of dwellings in Japan may increase in the future as the most drastic modifications to construction policies happened forty years ago, which is more than the current average house span life (Kobayashi, 2016:11,22,28; Lam, 2017). Moreover, there is a recent re-appreciation of old (timber) traditional buildings as a response to their constant abandonment and demolition (Berg, 2017). However, the Japanese dwelling's lifespan might remain as short as the scrap and build attached to their lifestyle (Yoneda & Serwta, 2019; Umeda, 2013:24,38,44).

Dwellings in Japan have a shorter life span than in the UK because they lose value with time. Japanese dwellings lose half of its value in ten years and become worthless in 25 years. On the contrary, UK properties gain value. From 1988 to 2018, the typical semi-detached dwellings in the UK increase their value by six times (Crossley-Baxter, 2018a). The house price per income ratio in the UK is of 108%, while in Japan it is of 102%.

Besides, the house prices compared to the countries' GDP per capita are lower in Japan than in the UK. It means that the Japanese find housing more accessible; which is a combination of housing need with higher structural standards against natural disasters, houses in Japan are considered disposable consumables (Yoneda & Serweta, 2019).

UK dwelling life and appreciation for existing housing stock

In the UK, properties constitute the entity of house and land, and this is how they are valued. Property prices in the UK are rising, and people do not consider new houses to provide significant advantages in comparison to existing dwellings, causing these to be highly valued and preserved (Bachelor, 2013; Graef, 2012). Old traditional houses are assumed to be better build even though they may have poorer insulation.

In the UK, traditional construction systems, like masonry, to last for a long time because the British islands do not experience natural disasters (Thomas, 2016). Rebuilding is considered an unnecessary expense as the value of properties mainly increases with land inflation rather than on the buildings' condition (Jefferys et al., 2014:32; Thorpe, 2016).

In the UK, the guarantee of increasing value in properties drives the desire to keep properties for a long time. Owning a house in the UK is seen as a secure investment that contributes to family assets. This debt culture, in conjunction with cultural aspiration factors, keeps ownership desire high (Poirier, 2016).

Housing transaction market

In Japan, new-build houses count for around 80% over the total housing transactions, while in the UK it counts for only 5% (House of Lords, 2016:25-26; Barlow & Ozaki, 2001:9; Boyce, 2018).

In Japan, selling a second-hand house is rare, while in the UK is the most common practice, not only compared between each other but also to other countries. The chart below shows the Japanese and UK housing transactions in comparison to the USA and

France, where Japan presents the highest percentage of housing starts in relation to the total transactions; while the UK is among the lowest (Fig. 74).

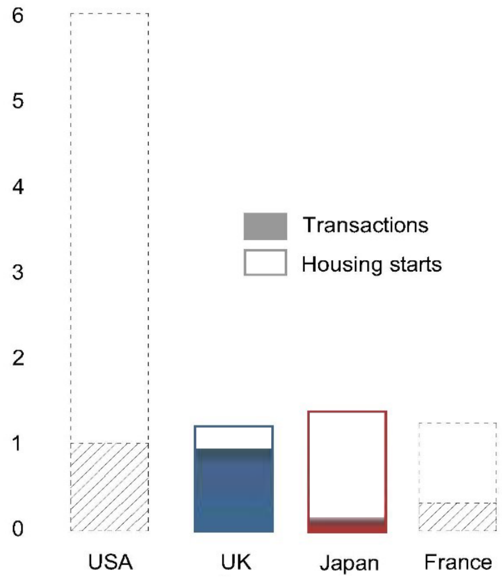


Figure 74. Size of the Housing Market in Terms of Transactions, in a million units (diagram by Author with information from Kobayashi, 2016:10).

The reasons for such disparate conditions are related to the lifespan of dwellings, properties' value change and cultural patterns.

In Japan, multigenerational living is common. There is a strong pattern of people living with their parents for a long time, even after getting married. Houses, where two or more generations live together, are called *'nisedaijūtaku'* (Jiji, 2018).

Japanese people tend to move houses rarely. Internal migration in the UK counts for 3.5% of the population every year, while in Japan counts for less than 1% (Kirk, 2015). The Japanese cultural pattern of multigenerational living is changing; however, moving from *home* is still unusual (Crossley-Baxter, 2018b). Japanese people have developed strong attachments to their land; if they want to "move" to a new house, they prefer to demolish where they live and rebuild (Barlow and Ozaki, 2005:11; Johnson, 2007:14). Subdividing plots is also a common practice. An existing house could be demolished to allow two new buildings to take place (Lam, 2018; Barlow et al., 2001:9; Lam, 2017).

In Japan, the moving rate and the dwelling lifespan are similar, which means that most probably a house owner will live in a house for the entire house lifespan. In the cases where house owners need to move places, and their dwelling have lost value in the marketplace, these are abandoned (Fleming, 2018; Harding, 2015; Tiwari, 2000:68,85-86; Gleeson, 2018). Abandonment rate in Japan counts for 13.5% while in the UK counts for 2.5%.

In the UK, people move around seven times in their lifetime, which means they move around every ten years (Walden 2019; Cutmore, 2017). Only three European countries have higher moving rates— Finland, Sweden and Switzerland (Masters Removers Group, 2019).

The moving ratio in the UK is higher than the dwelling lifespan. People in the UK would most probably move and sell the dwelling a long time before the dwelling reaches its lifetime. Houses in the UK are considered economic investments, not only a need. Houses are bought to be eventually transferred to someone else or for rental purposes. In the UK, house ownership is related to ‘property ladder’ behaviour, where house buyers expect a property with higher value with each move (Hale, 2019).

The housing need for each context

The following table describes the main conditions that determine the particular housing needs of Japan and the UK (Table 10).

Table 10. Japan and UK socio-economic comparison about housing (Sources: Countryeconomy; Projectbritan; Trading economics; The Telegraph; The Independent; opendemocracy; positivemoney; housebuyerbureau; and Pryce, 2003:572).

	Japan	UK
Housing starts per year	970,000	152,400
Average dwelling life	30 years	> 60 years
New-builds over total annual transactions*	80%	5%
Resale market (percentage of houses)*	14%	>80%
Ownership rate	60%	68%
Housing vacancy ratio	13.5%	2.5%
Houses Commissioned / Speculative	75 / 25 %	10 / 90 %
The average area of dwelling (sqm)	89.6	97.6
Size of newly constructed houses (sqm)	125	95
House price compared to 20 years ago	< 0.45%	> 200%

**Mismatch caused by housing voids, rounding of data, interpretation of sources and unsettling data factors as the adjustment of new-builds and demolitions into the total housing stock*

In Japan, the housing need is not a matter of supply and demand as these are even. Japanese have a high need for new houses because their dwelling lifespan is very short and because they need a constant updating of the housing stock to improve its resistance against natural disasters. Therefore, there is a need for house manufacturing in Japan to cope with the volume needed and for technology to build more resistant houses.

In Japan, the property ladder cycle broke after the bubble burst. Existing houses are replaced with new houses in the same plot to accommodate more effectively to the owner's new wants and needs, but not to provide them with an economic status

(Hirayama, 2010:180). Houses are considered personal and not transferable possessions most probably self-build.

In the UK, the housing supply does not match with its demand. There is a need to increase housing supply to double its current production. Housing prices respond to supply and demand. The housing value in the UK is rising exponentially. There is a need to stabilise the prices of the real estate market to avoid a bubble burst situation, like the one present in Japan in the 1990s.

The lack of supply in the UK is altering the market in price but not in quality (Geraghty, 2018). In the UK, the operational costs contribute to 52% of the total life cycle costs, of which half is from energy use. Fuel poverty affects four million households, which accounts for 15% of the housing stock. Thus, there is a need to improve the energy-efficiency of houses in the UK. Fuel poverty is also present in new houses. The UK has the need to improve quality in all spectrums of the housing market.

In the UK, manufacturing production is used to reduce construction costs; however, these savings are not reflected in the market price of the houses. Benefits of manufacturing, such as better quality and higher production, are also not reflected in the housing market. Houses are built smaller than the existing stock and with similar insulation technology.

Impact on energy efficiency

Japan and the UK have agreed to reduce their CO_2 emissions by setting different compromises that involved the housing sector (United Nations, 1998:20; iea, 2015:2). Accordingly, both countries have introduced legislation to control and reduce energy consumption in the housing sector.

UK evolution of energy legislation in housing

In 1965, 'The Building Regulations 1965' introduced the first limits on the amount of energy to be transferred through construction elements of new houses, expressed as 'U-value'.

In 1988 and 1989, the UK privatise the energy services. Average household electricity bills fell by 15-17% in real terms between 1990 and 1991. The energy bills continue to fall until 1998; however, these price falls were also due to the impact of stronger regulation (Pearson & Watson, 2012:20).

In 1994, following the publication of the '1993 White Paper' and the United Nations Framework Convention on Climate Change at Rio in June 1992, the UK government compromise to reduce carbon emissions into the atmosphere; therefore, a VAT tax of 8% was imposed on domestic energy (Pearson & Watson, 2012:14).

In 1994, the first 'Energy Efficiency Standards of Performance' (EESoP) was introduced in the UK. These programmes consisted of energy-saving obligations for energy suppliers (Rosenow, 2012:373). The first EESoP lasted from 1994 to 1998, the second from 1998 to 2000, and the third from 2000-2002. The three EESoP focused on saving electricity, while the third programme also focused on saving gas (Ofgem, 2003:15).

The EESoP got replaced with the ‘Energy Efficiency Commitments’ (EEC) and ‘Carbon Emission Reduction’ (CERT) programmes. The first ECC programme ran from 2002-2005, the second from 2005 to 2008, and the CERT from 2008 to 2012. These covered domestic electricity and gas distribution (Rosenow, 2012:376,379). These programmes promote energy saving through the application of energy-saving strategies. As an example, the savings of the second EEC were distributed with 56% of the saving made through insulation measures, 9% through the implementation of more efficient boilers, 11% though subsidised energy-efficient appliances, and 25% through energy-efficient lightbulbs (Chan, 2005:49; Pearson & Watson, 2012:23).

Energy prices continued to rise throughout the 2000s, with oil prices hitting a high of $147 per barrel in the summer of 2008. (Pearson & Watson, 2012:27). In 2003, the UK government published the ‘Energy White Paper’ with plans for a 60% reduction of CO2 emissions by 2050 (Chan, 2005:41).

In 2006, the government established the ‘Zero Carbon Hub’ and introduced the ‘Code for Sustainable Homes’ to enhance environmental sustainability in new dwellings. The Code for Sustainable Homes was a method for rating the environmental performance of new houses (Martiskainen & Kivimaa, 2019:1407). The government announced that all new houses should be built to ‘zero carbon’ standards by 2016.

In 2007, the UK also introduced the 'Energy Performance Certificates' (EPCs)— known as the European star rating scheme— to promote consciously, informed decisions on energy consumption. Since then, all buildings in the UK require an EPC before being sold or let.

In 2012 the 'Department of Energy and Climate Change' launched a scheme to finance energy-efficient improvements in houses called 'The Green Deal'. Green Deal programme was founded by the then Department for Energy and Climate Change. It was an initiative to give house owners and tenants the opportunity to pay for energy efficient dwelling improvements through the savings on their energy bills. The improvements covered included heating systems, building fabric, lighting and water heating (Martiskainen & Kivimaa, 2019:1408).

However, by 2015 the Green Deal was scrapped, and the Code for Sustainable Homes withdrawn. This later got removed a few months before it makes mandatory to achieve zero carbon standards in all new dwellings. The following table compresses the evolution of the energy programmes of the UK (Table 11).

Table 11. History of energy programmes focused on the domestic sector in the UK (sourced from Rosenow, 2012:379; Ofgem, 2003:8-9).

Programme	**EESoP 1**	**EESoP 2**	**EESoP 3**	**EEC 1**	**EEC 2**	**CERT**	**Code for Sustain able Homes**	**EPCs**	**The Green Deal**
Period	*1994-1998*	*1998-2000*	*2000-2002*	*2002-2005*	*2005-2008*	*2008-2012*	*2006-2015*	*2007- ongoing*	*2012-2015*
Target	Reduction of 6.1 TWh from electricity (lifetime)	Reduction of 2.7 TWh from electricity (lifetime)	Reduction of 4.9 TWh from electricity and 6.1	Reduction of 62 TWh from gas and	Reduction of 130 TWh from gas and	Reduction of 293 TWh from gas and	All new houses to achieve 'zero	Promote consciously, informed decisions on	Finance dwelling's improvemen ts that contribute to

			TWh from gas (lifetime)	electricity (lifetime)	electricity (lifetime)	electricity (lifetime)	carbon' standards from 2016	energy consumption	energy savings
Target group	Public electricity suppliers	Public electricity suppliers	All licensed gas and electricity suppliers with at least 50,000 domestic customers	All suppliers with over 15,000 domestic customers	All suppliers with over 50,000 domestic customers	All suppliers with over 250,000 domestic customers	Housebuilders in England and Wales	House owners and potential buyers	House owners in England and Wales

The UK legislation has also established a set of thermal regulations for new buildings, which are set in U-values (Ofgem, 2003:8-9). The following table shows the evolution of the U-values requirements and the current maximum for England as an example (Table 12).

Table 12. Evolution of U-Value standards in England for new dwellings (sourced from Ofgem, 2003:8-9).

Introduction		***1965***	***1976***	***1985***	***1990***	***1995***	***2002***	***2010***	***2013 (2016 amended)***
Socioeconomic background		The Building Regulations 1965	The 1973 oil crisis						
U-Value requirement (W/m²K)	Wall	1.7	1.0	0.6	0.45	0.45	0.35	0.28	0.18
	Ceiling	1.4	0.68	0.35	0.25	0.25	-	0.18	0.13
	Floor	1.2	1.2	1.2	-	-	0.51	0.22	0.13
	Window / door	4.8	4.8	4.8	-	-	2.0	2.0	1.4
Additional notes					Area of windows should not be more than 15% of the floor area	Limit on window area was raised to 22.5%	Limit on window area was raised again to 25%		

In the UK, the current legislation centres on ensuring a minimum quality in construction fabric. In practice, these are taken as baseline standards, housing constructions comply with the requirements but usually do not exceed them. Projects that achieve energy qualities beyond the standards are designed and constructed in accordance to the client's specification, such as Passive House standards, which are usually local councils (Martiskainen & Kivimaa, 2019:1409-1410).

Energy legislation in Japan

In Japan, there were no thermal regulations for building before 1980. Different to the UK, energy regulations in Japan are not mandatory for all dwellings. Only buildings with areas over 300 square meters need to comply with energy regulations; where new houses in Japan has an average of 125 square meters. Houses under 300 square meters can attain to the energy standards voluntarily. Only 23.5% of all new housing starts got evaluated every year (Huang et al., 2016:1513; Murakoshi et al., 2010:272,276; Sunikka-Blank & Iwafune, 2011:352; Ito, 2013:8,16).

In Japan, energy legislation centres in regulating the energy used by appliances. There are three evaluation systems. The minimum standard value under which all machinery, equipment, and other items covered should exceed standard values. An average standard value system under which the average value of all machinery and equipment should exceed average values. A maximum standard value system, also known as 'Top Runner Program' (Ministry of Economy Trade and Industry, 2015:6).

The Top Runner Program was introduced in 1999. The Top Runner program is like the Energy Performance Certificate present in the UK, as it is a labelling system to stimulate the consumption of energy-efficient products (Nordqvist, 2006:5; Murakoshi et al., 2010:272).

These energy evaluation assessments are regularly updated to include a broader range of electronic equipment in their calculations to increase the quality of the standards. They consider electrical equipment like air conditioning, refrigerators, rice cookers, computers, microwaves, electric toilets; and gas appliances as space heaters, gas cooking appliances and water heaters.

Japan possesses different active funding programmes and grants to promote higher energy performance of new buildings. Among those, there is the ‘Zero-energy housing promotion grant programme’ which was launched in 2012 (Ito, 2013:6,17).

In Japan, the implementation of environmental policies is voluntary, but 80% of the building meets the standards (Huang et al., 2016:1514). Thus, the low heating demand per household present in Japan seem to be due to different behavioural culture. As an example, the ‘Cool Biz’ is a voluntary energy-saving programme in Japan, that consist of setting the air conditioning to 28 degrees and casual clothing in the commercial sector. This programme has saved 460 000 tons of CO_2 per year. A difference between Japanese culture and energy consumption in the UK is that Japanese focus on ‘person heating’, while the UK traditions focuses on space heating. It means that the Japanese prefer to heat one room rather than the whole house. Heating the whole house is considered a wasting behaviour. As an example, 76% of the Japanese households are heated using the traditional ‘kotatsu’ heating— low table with heating under covered with a kilt (Sunikka-Blank & Iwafune, 2011:355). The kotatsu, for example, is a Japanese tradition that reduces energy consumption because they only heat the area under the kilt instead of the whole house.

Energy costs and energy selling prices

Energy consumption, considering only gas and electricity, is higher in the UK than in Japan. However, energy consumption in Japan counts for a higher percentage of the household’s income, which is around 10% compared to 4% in the UK. The following table presents a comparison of energy cost and consumption of dwellings in Japan and the UK (Table 13).

Table 13. Energy costs and selling prices

	Japan				UK			
	Gas	**Electricity**	**Total**	**% of income**	**Gas**	**Electricity**	**Total**	**% of income**
Annual consumption per kWh	12,000	2,300			12,500	3,100		
Annual consumption in currency	£450	£460	£910	10%	£475	£465	£940	4%
Cost per KWh in GBP	£0.03	£0.20			£0.04	£0.15		
Production in GBP pence per kWh		£0.35*				£0.05		

Notes: Calculations for the average 3-person household.
***Tariff-in value of energy from solar PV systems of less than 10kW.**

Energy prices are rising in both countries. In the UK, real prices for domestic energy increased by 34%, with the real price of electricity increased by 35% and the real price of gas increased by 32%; between 2007 and 2017 (BEIS, 2018:41). In Japan, electricity production increased by 32% from 2009 to 2015 (EIA, 2016).

The feed-in tariff for renewable electricity is higher in Japan than the UK, and more significantly, it is higher than the cost of domestic electricity. It means that households can get money if they produce the same amount of energy that they consume from the grid (Murakoshi et al., 2010:279).

The feed-in tariff scheme affected the housing market. Today, most Japanese housing companies include PVs as standards and have launched zero energy and zero-carbon models into the market.

The interest of Japanese house manufacturers in energy efficiency

Japanese house manufacturers use sustainability and energy efficiency for their marketing potential (Knaack et al., 2012:54-55). The residential standards were amended in 1992 and 1999, the Housing Performance Indication System got implemented in 2000, the Comprehensive Assessment System for Building Environment Efficiency in 2001, and more significantly, the feed-in tariff scheme was enacted by the Japanese government in 2002 (Ito, 2013:6). Consequently, between 1994 and 2003, houses delivered with photovoltaics (PV) in Japan increased from 539 to 52,863 (Noguchi, 2013b:167-168).

Sekisui House leads the commercialisation of nZEB and ZEB houses in Japan. Since 2003, all Sekisui House houses are built following internal energy standards. Since 2005, Sekisui House has followed initiatives to produce more energy-efficient housing that allows them to increase their reputation as receiving the ‘Promotion of Measures to Cope with Global Warming’ award in November 2016 (Farabi-Asl et al., 2018:99).

Japanese manufacturers also respond to government initiatives and funding. As an example, Misawa introduced its first solar home in 1974, as part of the ‘Sunshine Plan’ programme funded by the government to promote solar power energy sources following the oil crisis suffered in 1973 (Mihut & Daniel, 2012:1042; Sinha, 1974:343). Since then, energy efficiency was a marketing concern. In 1990, Misawa displayed a Zero-Net Energy prototype at an international exposition as a marketing strategy (Buntrock, 2017:206).

The offer of Japanese manufacturers involved in housebuilding extends beyond solar panels. In 2008, Sekisui House announced their so-called ‘Zero Emission House featured with a 14.5 kWh photovoltaic power generation system. Currently, Sekisui House markets the ‘Green First Hybrid’, which is equipped with roof tiles photovoltaics and storage capacity range from 4.6 to 9.3 kWh. In 2014, the Green First Hybrid houses represented 50% of their detached builds (Aitchison, 2018:115-116; Noguchi et al., 2016b:357-358; Knaack et al., 2012:54-55). Yamatake Corporation— a provider of automation components for buildings— commercialise an energy monitoring and control system that allows owners to estimate heating, ventilation and air-conditioning energy use, as visualising energy consumption reduces it by 10%.

Misawa Homes monitoring system display consumption on room-by-room energy consumption, including appliances consumption, production of photovoltaics, solar surpluses and CO_2 graphics (Sunikka-Blank & Iwafune, 2011:356).

Various energy efficiency technologies, as photovoltaics or 'smart' monitoring systems are dependant to manufacturing production. Technology tends to get cheaper with the pass of time, allowing new dwellings to include better technology at achievable prices. Japanese manufacturers include energy-related technology to increase their sales by providing more attractive products (Noguchi, 2013b:164-172; Moniz, 2015).

Summarising table

The following table presents a comparison of the Japanese and UK housing contexts, briefing the chapter information into key aspects. The table summarised the data presented in this chapter by highlighting the similarities and differences of both contexts (Table 14).

Table 14. Comparison of key similarities and differences between Japan and the UK housing contexts.

	Similarities	Differences	
		Japan	UK
History of housing from postwar times to the present day	-Use of prefabricated construction systems to overcome the housing crisis after the Second World War	- Continue using manufacturing systems to supply housing - House manufacturers provide 15% of the housing and are immersed in the self-build market - land prices peak in 1992 and decline after that; land value is currently stable	- 'Prefabs' programmes were dependant to government, and local authorities stopped building in the 1980s - The housing market is dominated by the speculative sector - Property prices are rising
Land effect on housing processes		- Land scarcity: topographic and geologic limitations for urbanisation - Housebuilders compete in price	- Land controlled by developers - Housing developers compete on land control

		and quality - Dwellings and land are valued separately - Self-builders represent 75% of the housing market.	- Properties are valued as an entity: house and land - The speculative business represents 90% of the housing sector - Speculative control is provoking constant rise on land value
Planning Systems		- Planning system centred on landowner and freedom to build - Planning systems encourage the fast reconstruction of housing stock - Heterogenous housing typology	- Planning system controlled by planning authorities - Self-builders find the planning system as a barrier
Housing need		- Need for high housing production; over 950,000 per year - Constant reconstruction due exposure to natural disasters - Housing and housing processes to accommodate the ageing population - Preference for new housing	- Housing deficit of 250,000 houses - Need for affordable housing (to increase ownership in young generations) - Preference for existing stock
Impact on energy efficiency	- Government compromise to reduce carbon emissions	- Houses under 300 m2 are not assessed through energy standards - Legislation focuses on appliances energy efficiency - Domestic energy production feed-in tariffs are higher than electricity prices	- Mandatory U-value construction standards - The legislation focuses on thermal fabric performance - Domestic energy production feed-in tariffs are lower than electricity prices

It is observed that there are more differences than similarities among both contexts. One of the main similarities is that both countries opted for prefabricated construction systems to overcome the housing crisis presented after the Second World War. Since then, the prefabrication sector has contributed to a fraction of the new housing stock in Japan; while in the UK, it was dramatically reduced after the termination of the Prefab programme and the collision of Ronan Point.

The other common aspect consists on the increasing regulation related to energy efficiency and towards a reduction of carbon emissions. However, the regulation and policies have been applied to very contrasting ends. In Japan, most regulation have been implemented to control energy consumption of appliances, while in the UK to ensure insulation and airtightness in constructions.

In terms of the effect of land on the housing process, planning systems and housing needs, the contexts are different and polar to each other.

Conclusion

The housing environments in Japan and the UK are very different and distinctive. Japan has particular geologic and topographical conditions, that in combination with its high population, limit their availability to land. In the UK, developers' land control restricts urban development. Accordingly, 90% of the housing market in the UK is covered by land speculators and few companies, while in Japan, 75% by a wide range of self-builders, including manufacturers. Interestingly, both countries opted for prefabricated construction systems to cope with the housing deficits carried after the Second World War. However, only the Japanese manufacturing sector continues producing houses on a large scale. Japan recover from the war housing deficit in the 1970s, while the UK has had a deficit since then.

Japan requires a high production of houses due to the short lifespan of their buildings and constant increase of construction standards; while the UK annual housing deficit could be covered with half of the percentage of housing production of the Japanese manufacturers.

Energy legislation in Japan set the domestic energy production at a higher cost than the one provided to the customers. Energy prices represent a higher income percentage in Japan. Consequently, the inclusion and quality of energy features are highly appreciated in the housing market.

This chapter described the differences between the Japanese and UK housing contexts to make visible the circumstances that allow manufacturing housing practices to exist in Japan and the potential niche for these strategies in the UK. The following chapters inquire on the technological and production capacities of both contexts describing the relation of mass customisation to these technologies and the capacity of the UK to include mass customisation within their production capacity.

The relevance of this chapter relies on setting a background to understand the differences between the housing models in Japan and the UK. Without establishing these parameters the comparison of the housing models would miss objectivity and fall into arbitrary conclusions. The following chapter presents a macro description and comparison of the speculative housing model in the UK and mass customisation model present in Japan. The comparison of both models requires a background to understand the reason why these are as important as they are in their own context and why they are not (strongly) present in the other. It also describes the risks of investing in technology for the construction of houses. This chapter provides the historical background to understand that the current technology used in the prefabrication of houses relates to historic and political conditions that where not present in the UK; and that therefore, its adoption might not result in a positive outcome.

Chapter 5

Macro description of housing models and why the transfer of Japanese manufacturing technology is not on

This chapter provides a descriptive comparison of the speculative housebuilders in the UK and Japanese mass customisers housing models and explains why the implementing of industrial machinery aspects present in the Japanese housebuilding are not appropriate for the UK context. It starts by describing their selling process from a customer perspective and the procurement processes. This chapter continues by explaining the risks of investing in manufacturing technology and machinery in the housing industry using examples. Then, it describes how the investment of Japanese house manufacturers in heavy industrial machinery is detached from their approach to mass customisation. It describes the importance of lean and agile manufacturing systems and how these are not strictly attached to investments in industrial machinery. This chapter finishes by explaining the importance of market-orientation in mass customisation, describing how Japanese house manufacturers invest in marketing and co-design processes.

Introduction

As explained in chapter 4, the Japanese and UK housing contexts have multiple differences. In the UK, the speculative housing sector accounts for 90% of the new houses and its business focus on land speculation (Ball, 2003:908–909; DCLG, 2017:13; McKibbin, 2018). These housing developers use traditional on-site construction procurement processes because these are the most cost-effective solutions available, predictable and well-understood (Lang et al., 2016:1246).The speculative housing industry in the UK has proved unwilling to adopt off-site production processes, which are proposed as a solution to increase housing production and dwelling's energy performance (Farmer, 2016:09; Pitts, 2017:10; Pan et al., 2004:125-126; Goodier & Gibb, 2005:148-149; Lang et al., 2016:1251).

In contrast, the house manufacturing sector in Japan uses off-site production process and have the capacity to produce large production volumes with energy performance levels that overpass the established standards (Bock & Linner, 2015:93; Aitchison, 2018:95-96; Noguchi et al., 2016b:354). Japanese house manufacturers that participate in the self-build sector has a very distinctive procurement method where they use robust manufacturing processes to produce houses customisable houses, also known as 'mass customisers' (Haug et al., 2009:633-634; Buntrock, 2017:192-203).

It has been continuously stressed that sophisticated and modern production methods in the housing industry lead to mass customisation (Farmer, 2016:11; Pan et al., 2008:17; Wang et al., 2017:311-312,320; Nahmens & Mullens, 2008:84-85; da Rocha et al., 2015:4920). The industrialisation of housing 'promise' not only to achieve mass customisation but to improve environmental performance and energy efficiency (Aitchison, 2018:13). However, there is the question of how sophisticated and technologically advanced these production processes need to be to allow mass customisation and zero energy.

This chapter describes the procedures and composition of housebuilders and developers in the UK and mass customisers in Japan. It highlights the differences in manufacturing capacity among both contexts, to explain why implementing technology and machinery that resembles the Japanese mass customisation could financially endanger housebuilding companies in the UK.

UK speculative housing

Housing developers compete on land control. Thus, the speculative business requires high investment, not only to buy large portions of the land but to bank them for long periods of time. It is common for housing developers in the UK to have their companies listed in the exchange stock, which force them to pay back the bank and shareholders an established amount of money (Parvin et al., 2011:26-27). The following graphics describe how the speculative housing business needs to prioritise land value and profit over manufacturing capacity and how the cashflow drives the procurement process (Fig. 75).

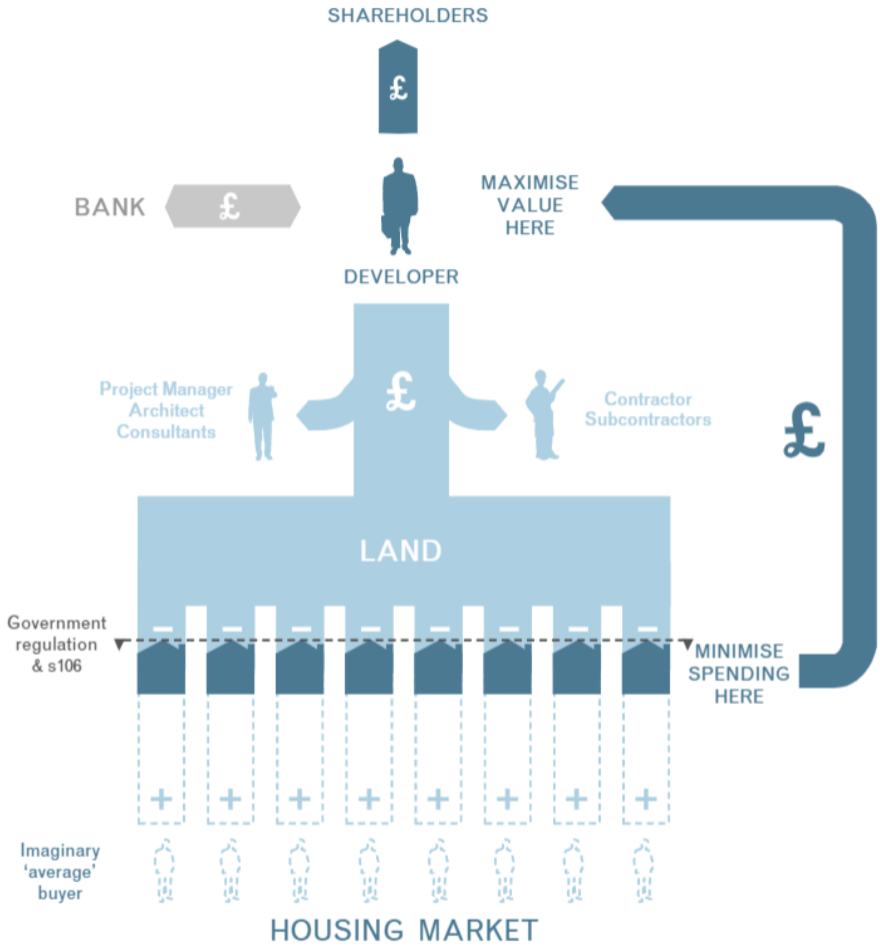


Figure 75. Speculative sector cash flow (from Parvin et al., 2011:27).

Description of housing model

In the UK, the acquisition of a new house is less complicated than self-building from an end-user perspective (Noble, 2017). First, (1) house buyers select from the stock of properties offered in new developments. (2) House buyer's that cannot pay with cash contact a mortgage adviser and agree a mortgage in principle, and (3) reserve a property. Then, (4) they need to appoint a conveyancing solicitor, who will handle the legal procedures. (5) House buyers secure the mortgage and pay the house deposit. Then, (6) the solicitor will exchange contracts with the seller. Finally, (7) there is a process of completion where house buyers and sellers agree to a handover day. The following diagram describes the buying process of mass housing in the UK, accompanied by a table presenting the buying steps, its costs and expected times (Fig. 76 & Table 15).

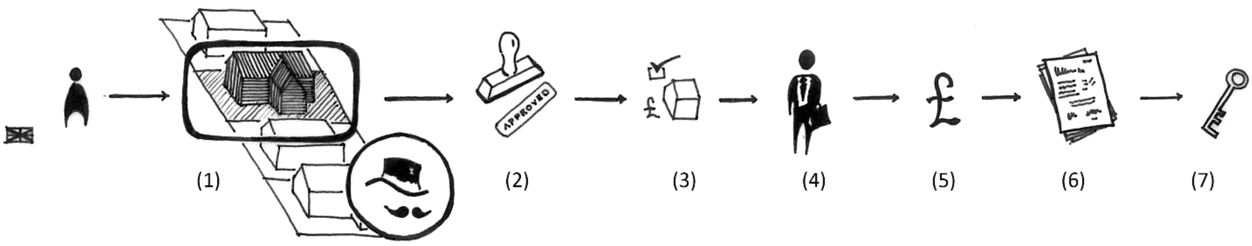


Figure 76. House buying process observed in the speculative sector of the UK (by author).

Table 15. House buying process times and costs (by the Author with data collected from Noble, 2017; Barratt Homes', 2016; the Money Advice Service, 2018).

UK (England, Wales and N.I. / Scotland)				
Steps			**Accumulative time (days)**	**Cost for Client (£)**
1	Financial research / Find a Solicitor		15	-
	Find a property	Research area / websites	45	-
		Visit homes / Showhomes		
		Check seller's Home Report		£400
2	Agreement/Mortgage/Decision in principle			-
3	Reserve property		28	£500-2000
4	Appoint a Solicitor	Booking fee		£99-250
		Valuation fee		£150-1,500
5	Secure mortgage	Mortgage account fee		£100-300
	Pay deposit			Agreed % of the house (usually 10%)
6	Exchange contracts	Negotiate completion date / Solicitors conclude 'missives'	25	Agreed % of the house (usually 10%)
7	Completion	Receive payment of the seller's solicitor	5	-
		Handover	7-240	-
	Pay mortgage		-	Agreed periodical

Procurement process

The procurement process present in speculative housing is complicated and segregated from the selling and marketing processes (Ball, 2003:908–909; DCLG, 2017:13; McKibbin, 2018). Housing developer's business is based on land banking, which affects the procurement process. Housing developers build less than 10% of the number of plots they bank.

The procurement process runs as follows. First, (1) housing developers identify portions of land with development potential. Then, (2) they secure outline planning permission and negotiate with landowners. Then, (3) bank these plots for some time until they can get the most profit from selling them. Eventually, (4) housing developers build houses on the plots of land. They hire external contractors, or in some cases using their construction team. Contractors and construction managers plan cost-effective and efficient supply chains, including reliable suppliers and proven construction systems. These houses are designed for an imaginary 'average' user (Parvin et al., 2011:24; Habraken, 1972:9-11). (5) Construction elements are produced in manufacturing plants; which in turn, are assembled from components and subcomponents from other manufacturers (Goodier & Gibb, 2005:157; Pan et al., 2007:3). Most of the procurement process— land acquisition, planning, design and construction— happens before the involvement of the final customer. (6) Housing developers sell houses from stock (Fig. 77).

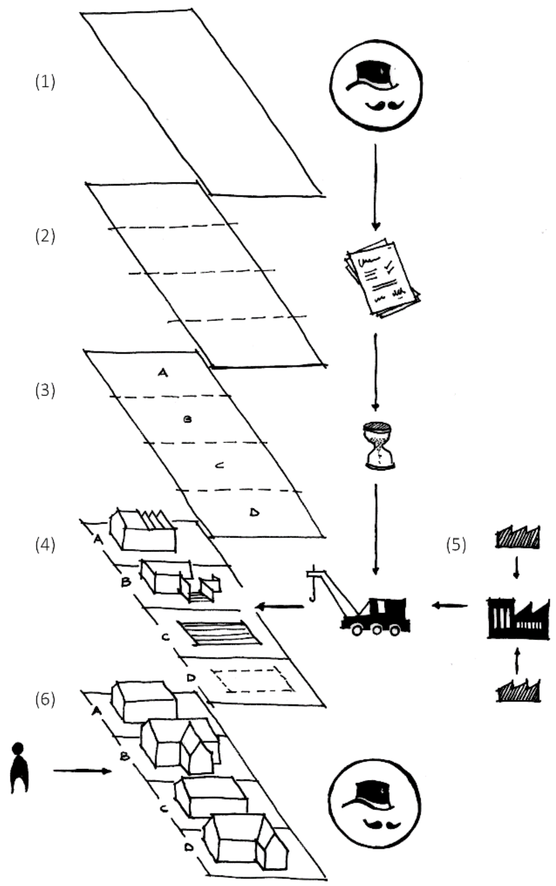


Figure 77. Procurement processes observed in the speculative sector of the UK (diagram by author).

Most commonly, the construction and the selling of the houses happen in parallel or at the same time (steps 4-7). It is in the interest of house developers to sell the houses as soon as they are completed. However, the design of the houses is highly pre-defined and expected not to change. Some housebuilders are allowing customers to make different decisions over the design of their houses, but are restricted to finishing details, like selection of carpets, bathroom tiles, wardrobe door style, garden design and upgrade of shower thermostat.

The housebuilder's role

Housing developers play the role of land promoters, acquiring land, procuring designs, securing planning permission, raising finance and contracting the dwelling, while marketing them to buyers. Developers control the entire procurement process, which involves managing risks. Developers are accountable for raising and managing funds and responsible for procurement times (Parvin et al., 2011:24).

The contractor's role

The role of the contractor in the procurement process concentrates in the management and construction of the buildings. Housing developers use their own construction team unless they do not have a construction workforce and equipment or the project overpass their capacity; in these cases, they subcontract independent contractors (Barawas et al., 2013:1-2).

The manufacturer's role

The manufacturers' role in the housing procurement process is to supply the contractor with construction parts and elements, including factory-assembled components as timber frame panels, structural insulated panels or truss-rafters. As an example, timber framing is the main off-site manufactured product utilised in housing development in the UK. It accounts for 66% of a new dwelling in Scotland, 20% in England, 27% in Wales and 22% in Northern Ireland (Hairstans & Sanna, 2017:225). The rest use traditional on-site methods.

Combination of roles: Merging tendency

There is a rising tendency for housebuilders, housing associations and contractors in the UK to invest in manufacturing plants or associate with manufacturers (Lewis, 2019; Wilmore, 2019; Bloxham, 2018; Collinson, 2018; Dransfield, 2018). As an example, Urban Splash— a British company, recognised for their urban regeneration projects— received an investment of £55m from the Japanese company Sekisui House, who took 35% equity stake in Urban Splash's modular House business (Ord, 2019; Barrett, 2019; Bloxham, 2018). The following table presents different the investment of different housebuilders into manufacturing (Table 16).

Table 16. Financial and investment data of manufacturers in the UK (Sourced from Lewis, 2019; Wilmore, 2019; Bloxham, 2018; Collinson, 2018; Dransfield, 2018; Ing, 2019).

	Business	*Factories (active from)*	*Investment*	*Size*	*Internal Production of material*	*Construction system*	*Product*	*Capacity*	*Employees*
NU Homes / Swan	Housing Association	1 (2017)	-	7,000 m2	No	CLT panels	Modular	500	40
Ilke Homes	Manufacturer	1 (2018)	-	25,000 m2	No	Timber frame	Modular	2,000	150
Legal & General	Multinational financial service	1 (not active)	£55 M	51,000 m2	CLT panels	CLT panels	Modular	3,500	-
Berkeley	Housing developer	1 (2020)	-	14,000 m2	light-steel frame	Steel frame	Modular	1000	200
Weston Homes	Manufacturer	1 (2019)	£12 M	7,000 m2	Processed wood and steel	Assembly of components	Construction components	-	60
Doncaster, Keepmoat & Elliott	Housing developer + Manufacturer	1 (2021)	-	25,000 m2	-	-	-	-	150
Urban Splash	Urban developer	1 (2018)	(£55 M investment from Sekisui House in 2019)		No	Steel frame and CLT panels	Modular	400	70

It is observed that investment in manufacturing systems in the UK does not follow a particular pattern, besides showing higher interest on modular construction, which probably indicate that investments are thought for mass housing models. Scale is small and dominated by companies investing in off-site manufacturing for the first time, and so, all the companies compared in the table above only possess a single factory.

Japanese Mass Customisers

The procurement processes of Japanese mass customisers are very different from the speculative housing sector in the UK. A determining factor is the land scarcity of the Japanese context. It is common for Japanese people to own a plot and use it to build a new house; where houses are valued independently from the land attached to it (Johnson, 2007:14; Barlow et al., 2001:9). Accordingly, Japanese people buy their houses directly from house manufacturers. The mass customisers' selling techniques are comparable to car manufacturers in the degree of customisation offered in the selling process (Brown et al., 2013:95; Parvin et al., 2011:53).

Description of housing model

Japanese house manufacturers build about 150,000 housing units per year. Compared to the UK market, Japanese house manufacturers build around the same number of houses that all housebuilders in the UK, even if it counts for only 15% of their house starts (Johnson, 2007:11-20). The companies that produce mass customisable houses have the highest turnover among housebuilders in Japan. These house manufacturers not only produce on-demand houses, but they are also estate agents, property lenders and housing developers (Bock & Linner, 2015:94-96).

Mass customisers are usually large manufacturing companies or subdivisions of manufacturing companies. The production of mass custom detached houses only covers a percentage of their business. Sekisui house, for example, custom detached houses accounts for 19% of their business, overpass by rental housing that accounts for 22% of their business and real estate management fees that accounts for 23%. For Daiwa House, the mass customisation production accounts for 11% (Daiwa House, 2017:11). Other business the Japanese house manufacturers include remodelling, construction of condominiums, construction of corporate facilities, urban redevelopment and overseas business (Sekisui House, 2017:6). Consequently, and considering the production volume of Japan; the Japanese manufacturers possess large scale and sophisticated construction and manufacturing plants (Buntrock, 2017:196-200; Aitchison, 2018:93).

The mass customisers' selling process runs as follows. (1) Customers who already own a plot, approach house manufacturers, who check that the customer possesses a feasible plot and planning permission and present him with a range of potential house designs. (2) The customer selects a model from the range offered by the manufacturer. At this point, customers sign a temporary contract, which stipulates the range of cost, delivery times, responsibilities of the customer and housebuilder. Then, there is a (3) process of co-design where the house is customised in terms of the plan, interior layout and choices on construction systems and materials. At this stage, customers specify technical aspects as the material used for structural systems, the thickness of insulation and technology for fire and earthquake resistance (Barlow & Ozaki, 2001:9). Then, customers with a mortgage or cash in hand (4) sign a definitive contract. Then, (5) more detailed customisation stages take place, where customers select architectural features, mechanical systems, renewables and agree to details, like the height of steps, handrail or kitchen bar (Bock & Linner, 2015:123-124). House manufacturers will then produce and (6) deliver the house or assemble it on-site. The following diagram and table represent the procurement and manufacturing process of mass customisers in Japan (Fig.78 & Table 17).

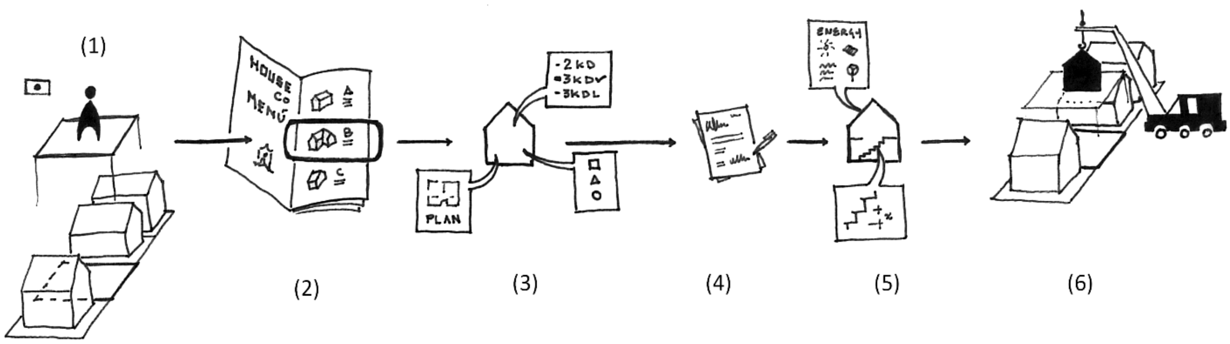


Figure 78. Buying processes from Japanese mass customisers (Diagram by author).

Table 17. House buying times and costs for mass customised houses in Japan (Data from Barlow & Ozaki, 2001:18— Figure 5 'Typical purchase process for customised housing').

<table>
<tr><th colspan="5">JPN</th></tr>
<tr><th colspan="3">Activities</th><th>Time (days)</th><th>Cost for Client (£)</th></tr>
<tr><td>1</td><td colspan="2">Landowners approach</td><td>-</td><td>-</td></tr>
<tr><td>2</td><td colspan="2">First Consultation</td><td>1</td><td>-</td></tr>
<tr><td></td><td rowspan="5">Pre-Planning and planning/building budget</td><td>Checking finances / Regulations</td><td rowspan="5">-</td><td rowspan="5">£300</td></tr>
<tr><td></td><td>Plot/Site survey</td></tr>
<tr><td></td><td>Drawing a basic plan / Sketch</td></tr>
<tr><td></td><td>Planning Permission</td></tr>
<tr><td></td><td>Decision on layout / Approx. cost</td></tr>
</table>

	Provisional Contract		50	£2,500
3	Detailed design	Detailed discussions on the plan	-	
		Choices over technology		
		Interior layout design		
4	Contract Signed		105	10% (house cost)
5	Final Design	Choosing finishes/colours	-	
		Checking plan/amendments		
	Notifying suppliers		135	
	Manufacturing / Construction	Commencement (5)	150	30% (house cost)
		Completion	-	30% (house cost)
6	Handover *(Including assembly on-site, finishing and landscaping)*		270	30% (house cost)

The procurement process of mass customised houses in Japan runs in parallel with the design and selling processes. Different from the UK, the construction/production of mass customised houses only starts when a customer agrees to buy a house.

Procurement process

The housing procurement process of mass customised houses in Japan runs as follows. (1) The customer approach the sales department of a mass customiser and (2) select a house model. The models presented to the customers are pre-designed by the housing company, including pricing and production schedules. (3) Once the customer signs a contract, a series of customisation stages take place. The customisation processes are designed following the company's solution space, as explained in chapter 3. The customers customise their house model through choice navigation tools and guides provided by the company. (4) The production process only starts when the customer decides on the house design. Once the preliminary design is set, (5) the company organises the signing of the contract, including final costs, payment methods, finance assistance, guarantees, insurance and delivery time. (6) The final design is translated into the production and assembling process. (7) Mass customisers' production lines are consistent but open to admit construction components from external suppliers. Thus, once the final design is set, external suppliers are notified about the dimensions, quantity and specifications of the required construction elements. Accordingly, (8) the external suppliers use production parts produced by other manufacturers. (9) The manufacturers manage the whole production process, which produces building components that are delivered to the site. Finally, (10) house manufacturers, or sub-hired contractors, assemble the building components on-site. The following diagram describes the mass customisers' procurement process (Fig. 79).

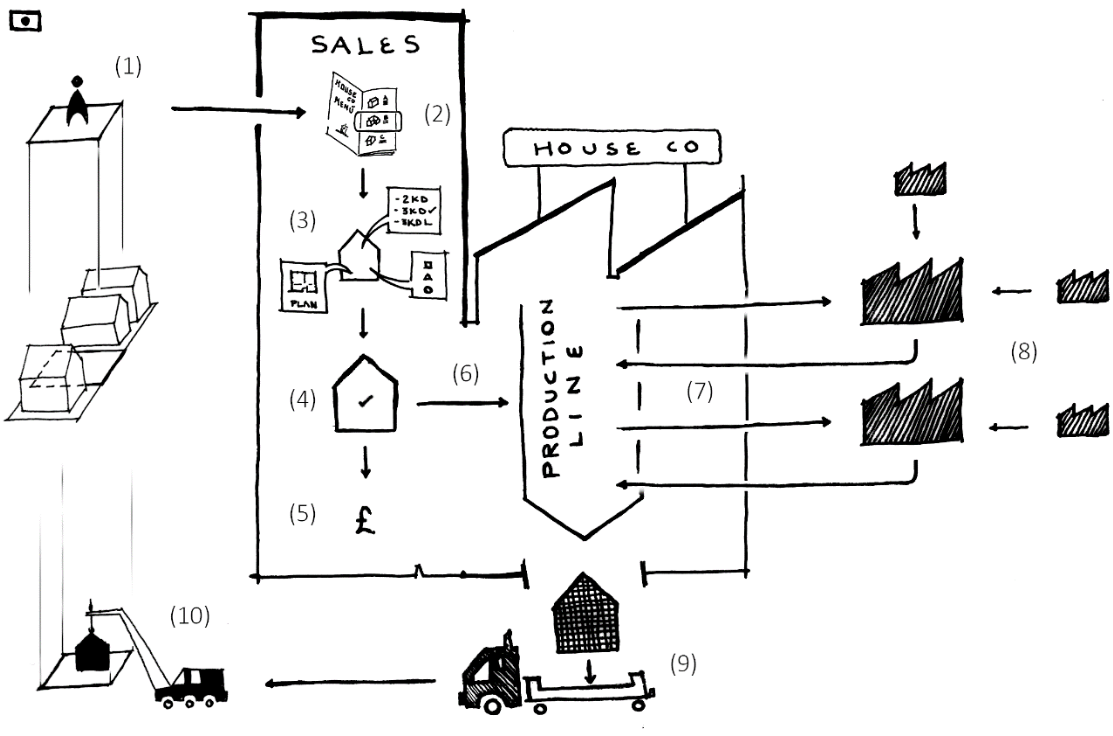


Figure 79. Mass customisers procurement process (by author).

The design and customisation processes require precise communication and organisation skills. House manufacturers possess sophisticated marketing/selling systems that not only clarify and accelerate the customers' decision-making process but keep the supply chain organised and running (Schoenwitz et al., 2013:436).

The manufacturers' ability to efficiently transfer the customer's design decisions to their supply chain is a central characteristic of mass customisation, which includes efficient communication with external suppliers and production lines adapted to external components (Bock & Linner, 2015:110-111,209). Most of the variability offered comes as a result of having production lines that admit components from external suppliers (Schoenwitz et al., 2017:82). Japanese house manufacturers add value to external components by assembling them with other components and include them as integral parts of the buildings (Noguchi, 2013b:172).

The mass customisers' business focuses on providing the services embedded in the selling process, such as design, financial assistance, warranty, post-sale services and maintenance (Sekisui House, 2018; Daiwa, 2017; Sekisui Chemical, 2017). Some house manufacturers, as Muji, does not even have manufacturing facilities, and subcontract the production to other manufacturers (Bock & Linner, 2015:95).

House manufacturers only sell detached houses through mass customisation systems. Japanese house manufacturers also produce dwellings for rental purposes and development of new land, including high-rises and multi-storey residential buildings.

Japanese mass customisers manufacturing capacity and flexible production lines

The Japanese mass customisers, integrate the production and manufacturing to their design and selling processes. Japanese house manufacturers are recognised for their manufacturing capacity, which is the most industrialised. They use automated production processes to produce a large percentage of the housing components on-factory with their own resources, which is particular of the Japanese context (Buntrock, 2017:196-200; Bock & Linner, 2015:96-98). The following images show the scale of the factories of Sekisui Heim, a Japanese house manufacturer (Fig. 80).

Figure 80. Different Factories of Sekisui's Heim (From Bock & Linner, 2015:185,197)Japanese house manufacturers have implemented industrialised and automated manufacturing systems from the 1960s; which grow significantly in the decades of 1970s, 1980s and 1990s (Linner & Bock, 2013:154).

The manufacturing processes used vary from company to company in relation to the time the technology was implemented and the orientation of their business. Thus, some companies used sophisticated conveyor lines and other production stations with robotic lines or mixed both (Davies, 2005:186; Bock & Linner, 2015:110-111). The following images show manufacturing approaches used by different house manufacturers in Japan (Figs. 81 & 82).

Figure 81. (left) Assembly area of a PanaHome factory using cranes and sophisticated conveyor lines (From Bock & Linner, 2015:163— Figure 5.34). Figure 82. (right) Assembly area of steel frames at a Sekisui House factory using Robotic processes without human intervention (Aitchison, 2018:94— Figure I.2).

For Japanese house manufacturers, most of the construction process happens off-site. All mass customisers use of lean manufacturing and postponement production processes, which allows them to manage efficient customisable production. It means they can only produce a house after an order has been placed; a ‘pull’ model instead of the ‘push’ model observed in the speculative sector of the UK (Davies, 2005:190-193; Aitchison, 2018:93-95; Naim & Barlow, 2003:600; Smith, 2009:178-183; Nahmens & Mullens, 2008:85). The type, capacity and investment on production lines are determined by the companies’ business model, financial background and targeted production; which, in turn, shape each company’s robust capacity.

Transfer of technology is not on

The Japanese housing industry has the manufacturing capacity to produce, both mass custom and zero energy dwellings (Bock & Linner, 2015:222-223). The industrialisation of housing in Japan is very particular to its history and economics

(Aitchison, 2018:74). As explained in chapter 3, the Japanese housing manufacturers exist, grow and maintain as its context has proved appropriate for it. The manufacturing capacity of Japanese housebuilders is drastically larger and more sophisticated than the present in the UK, as explained in chapter 5. However, this is not the case of every context, including the UK. The adoption of Japanese manufacturing capacity into the UK rises financial risks. More importantly, it does not ensure a successful application of mass customisation, neither the capacity to produce economically feasible zero energy dwellings (Zipkin, 2001:86; Salvador et al., 2019:34; Johnson, 2007:33).

As stated in previous chapters, the application of mass customisation requires three capabilities; the development of a solution space, a robust process and appropriate choice navigation tools (Piller & Tseng, 2010:4; Jensen et al., 2015:163). The UK possesses manufacturing and technological capacity to develop these capabilities. Thus, the differences in business volume, number of factories/employees, sophisticated methods of production and technological assets between Japan and the UK should not be a barrier for implementing mass customisation in the UK (Barlow et al, 2003b: 93; Ferguson et al, 2014; Blecker et al, 2004 :890, 897).

Risks and barriers of investing in manufacturing technology and machinery in the housing industry

Implementation of new technologies and machinery implies risks that could threaten the survival of companies. Housebuilders face different barriers that inhibit them from adopting sophisticated industrial methods of construction (Pan et al., 2008:24; Goodier & Gibb, 2005:153).

Most commonly, companies that invest in machinery and technology assets get loans or funding that compromise them to pay back in return. Their goal is to start or expand the business where those funds produce an increase in the companies' income and value over time. However, if the investment does not pay back, these companies risk financial problems and bankruptcy. Investments fail when these have a low market orientation or mismatch with the core of the business (Salvador et al., 2019:1; Chen, 2019; Budwell et al., 2016; Hecht, 2015).

Psychological and cultural bias that affects the correct investment in manufacturing

One of the main barriers for the adoption of machinery and technology is misunderstanding what can they bring to the housing business. Housing involves the interaction of multiple professions and disciplines. If the interest in prefabrication is driven by one or few of these professions and disciplines, the use of machinery and technology would have an unbalanced result. The interest of architects is different from the one of engineers, designers or investors (Aitchison, 2018:92).

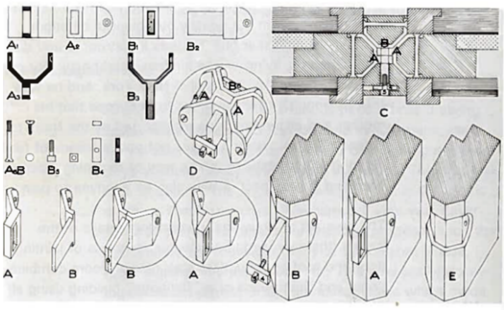
For example, in 1942, the 'General Panel Corporation' was founded in the USA with the intention to produce houses through industrialised methods. The concept was conceived by Konrad Wachsmann and Walter Gropius, well-known and respected architects, with support of investors, government and academics. The General Panel

Corporation was funded with 6 million dollars. Most of their investment was used to set-up a state-of-the-art factory that was expected to produce 10,000 houses per year; however, the company went into liquidation in 1951 with the production of fewer than 200 houses, where only a handful was actually sold (Herbert, 1984:265-267,306-307; Davies, 2005:19; Bergdoll & Christensen, 2008:82). The following image shows the General Panel Corporation factory 'Burbank' in California (Fig. 83).

Figure 83. General Panel Corporation Burbank factory in California, 1947 (From Herbert, 1984:291—Image 9.14).

The failures of General Panel are associated to: lack of understanding of the market, volume considerations which saw the resultant houses being more expensive than the housing market, reliance on a closed system, overheads incurred by factory production and gearing up, absence of detailed understanding of the regulatory and financial contexts, and the uniqueness of the product mismatch with traditional construction (Aitchison, 2018:54).

However, probably the main reason for the failure of the General Panel Corporation was Wachsmann’s obsession with developing an ideal construction system (Imperiale, 2012:43; Herbert, 1984:309). Wachsmann guided the company’s efforts to develop a joining system that would allow two-, three- and four-way connections between panels to connect all the main elements of the building— external walls, partitions, floors, ceilings, and roofs (Davies, 2005:19; Ågren & Wing, 2013:12). The following images present the evolution of the joining systems (Figs. 84, 85, 86, 87 & 88).



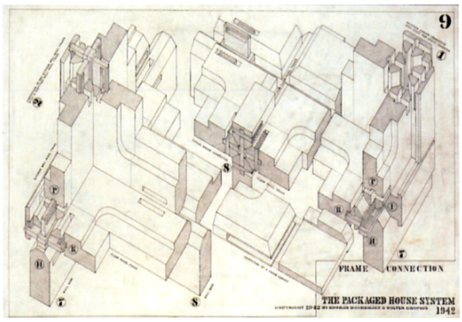
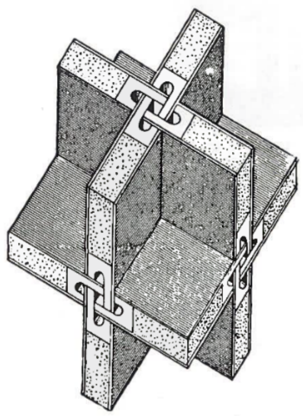
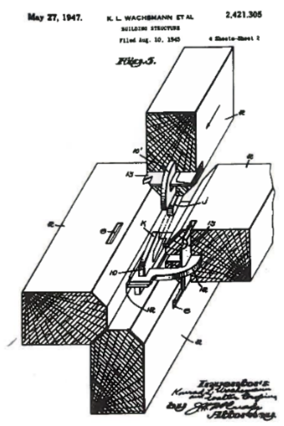


Figure 84. (left) Detail metal connector for the Packaged House, 1941 (From Herbert, 1984:250—Image 8.4). Figure 85. (right) Connection for the Packaged House ‘Type A’, 1942 (Bergdoll & Christensen, 2008:83).





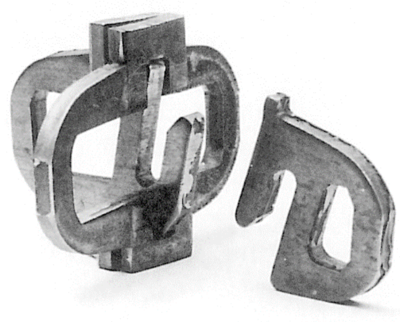


Figure 86. (left) Partition system for the General Panel Corporation, 1942 (From Herbert, 1984:273—Image 9.6). Figure 87.(middle) Wachsmann patent for building system, 1945 (From Herbert, 1984:274—Image 9.8).Figure 88. (right) Wedge connector for the General Panel Corporation (Bergdoll & Christensen, 2008:85).

Wachsmann interest in prefabrication focused on solving an engineering problem

(Davies, 2005:24). Gropius interest centred on achieving housing variability through standardised production (Gropius, 1935:40; Gropius, 1956:146; Pevsner, 1961:50-51). The investors' interest focused on generating profit through the sale of as many houses as possible (Aitchison, 2018:54-55,64).

The determination to have the *perfect* system and factory instead of using ad hoc solutions delayed the production and increased its costs, causing its eventual closing (Herbert, 1984:309). Wachsmann and Gropius focused on the object rather than on the objective, which was to build houses. By the time the General Panel Corporation existed, other companies in the USA had managed to produce houses through industrialised processes, like the 'Lustron Houses' and 'National Homes Corporation' of Lafayette, also in the USA (Davies, 2005:22-23). The National Homes Corporation construction system was less sophisticated than the General Panel Corporation; however, they delivered over 100,000 houses and were active from 1940 to the 1960s (Parsons, 2012; Romanski, 2018).

The success of the National Homes Corporation relied on using industrial production as a construction innovation, rather than inventing a new construction system as the General Panel Corporation (Aitchison, 2018:70). The National Homes Corporation construction system consisted of an industrialised version of timber frame systems used in construction by that time, like the 'Balloon Frame' (Davies, 2005:203). The following images show the resemblance of the National Homes Corporation construction system with the Balloon Frame system (Figs. 89 & 90).

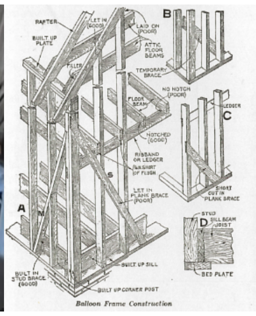



Figure 89 (left). National Homes Corporation timber frame production line, 1950 (Snapshot from Footage Farm, 2012). Figure 90 (right). Balloon frame construction system (From Bergdoll & Christensen, 2008:41).

Innovation refers to the application and uptake of technology, while invention refers to the action of inventing something new. National Homes' timber frame system was an innovation of the balloon frame, while the General Panel joining system was an invention. In the housing context invention struggles to result in commercial success (Aitchison, 2018:70). Most prefabricated house technologies are essentially new versions of the 170-year-old American balloon frame (Davies, 2005:203).

Construction systems need to guarantee its quality, at the moment of construction, and for years to follow. The failure of construction systems involves maintenance and repairs, which diminishes the profit. It also affects the reputation of contractors and manufacturers. Clear examples are the 'Oriental Masonic Gardens' by Paul Rudolph and the 'Nagaking Capsule Tower' by Kisho Kurokawa. Rudolph's system presented diverse fixing problems. Roof panels were not fitting to walls and structure, causing leaking of air and water. Residents were not satisfied, and the housing development got demolished just eighteen years after its construction (Collins, 1979). Likewise, Kurokawa's capsules present problems of leaks, rust and corrosion. The tower is covered with a net to avoid animals and small objects to get stuck in between the capsules which affect pipes. Nakagin Capsule Tower is inching closer towards a potential demolition (Soares & Magalhães, 2014, Ouroussoff, 2009). The following images show both projects (Figs. 91 & 92).

Figure 91. (left) Construction of Oriental Masonic Gardens, Connecticut, USA (Copyright of the Estate of Paul Rudolph, The Paul Rudolph Heritage Foundation). Figure 92. (right) Deterioration of the Nagakin Capsule Tower in Tokyo Japan, status 2016 (Photo by the author).

The president of the Coastal Modular Corporation construction company, that developed the Oriental Masonic Gardens, stated that they lost 400,000 dollars in the project and would not do something similar again (Collins, 1979).

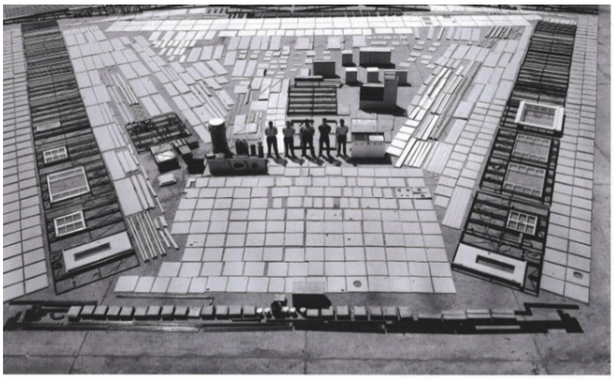
Companies tend to invest in the invention because they get influenced by the idea that the construction industry is on the verge of fundamental revolution. However, this discourse has repeated several times in the history of housing and architecture. In 1923, Le Corbusier (1974:250-269) stressed the urge for revolutionary adoption of mass production systems in housing and construction. The use of industrialised production has been promoted several occasions in the UK (Aitchison, 2018:61; Aitchison & Macarthur, 2017:77). Today, the UK housing industry is pressed to increase the use of 'Modern Methods of Construction', a term coined in 2003, as a solution to the under-supply and poor quality of housing (Pan et al., 2008:2; Oliveira et al., 2017:6,10; Reynolds & Tate, 2018:1,3; Barker, 2004:103),

There are many terms attributed to the innovative methods of production in the construction sector (Piroozfar & Farr, 2013:119; Farmer, 2016:5,12). Modern Methods of construction is a term coined to demise the term Prefab and its reputation (Jones, 2009:45). The blurred definition and pressure for using innovative construction systems push companies to invest blindly and precipitated in technology and machinery.

There is no agreed best-practice or -production process for housing. Houses are produced from a variety of materials, different than cars, for example, that are mostly produced from steel (Aitchison, 2018:81). Therefore, it is difficult to identify the most adequate and suitable production system.

Accordingly, new construction systems need to be open to compatibility with other construction systems. Closed systems that do not allow for the interchangeability of components or compatibility with other systems, present problems in practice. These also prove to be more expensive as they depend on the production of all components and cannot benefit from the low prices of mass-produced components.

The Lustron and General Panel houses increased costs were provoked by the closeness of their systems, which required the production of most construction components, including joining systems, cladding, and for the case of the Lustron houses counting for 3,000 parts including furniture, equipment and clips for mounting wall decorations (Wolfe & Garfield, 1989:56; Herbert, 1984:290-297). The following images present the unassembled parts of the Lustron and General Panel houses (Figs. 93 & 94).



5 Components of a Lustron House

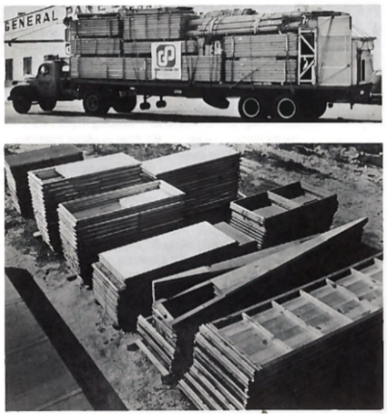


Figure 93. (left) Lustron House components for a full house, which could be assembled by five workmen (From Aitchison, 2018:55— 3.15). Fig. Figure 94. (right) General Panel house components on-site and fitted into a truck (From Herbert, 1984:294—9.15 & 9.16).

In Japan, housing systems are required to be compatible with other systems. In the 1970s, the Japanese government promoted research and development of ‘open systems’ encouraging companies to produce individual components rather than whole houses (Ryu, 1979:121).

Today, Japanese house manufacturers use components from diverse manufacturers. Japanese house manufacturing industry, which has existed for over 50 years, is heavily industrialised; however, their investment in technology has been gradually and progressive. As an example, Sekisui House motto is ‘slow and smart’, and the principle of the Toyota system is to use automation only when the human task has been perfected and deemed to have no handcraft value (Aitchison, 2018:78; Bock & Linner, 2015:141-142).

Cost and finance barriers

Investing refers to the allocation of funds to an asset with the expectation of generating an income or profit. Thus, investment is a matter of finance and economics. Successful investments are followed by a growth of the companies' assets, usually reflected on production growth (Picardo, 2019).

The UK has a large housing deficit. It is calculated that the construction industry requires to increase its productivity by 30% to produce 10,500 dwellings per month for the next 20 years; conditions that look appropriate for investment (Reynolds & Tate, 2018:3). However, as explained in chapters 4 & 5, the undergrowth of the housing market in the UK is caused by control of land and particularities of its context.

The housebuilding industry has proved that investment in machinery does not guarantee success even with high housing demands and apparently appropriate conditions. The General Panel Corporation is, again, a clear example. In 1947, when its factory was set for production, the USA had a housing demand for over 3,000,000 housing units (Wheildon, 1946; Herbert, 1984:290). The General Panel Corporation failure is related to diverse reasons, but mainly because they were unable to generate profit and pay back their investment.

The failure of the General Panel Corporation was a matter of sales and production. Other USA companies were able to produce and sell houses in the USA in those times. The Lustron Houses managed to sell around 2,500 houses, but like the General Panel Corporation, they went to bankruptcy in 1950 after a short period of production due incapability of making a profit from its investment (Davies, 2005:59).

The Lustron House company was directed by Carl Strandlund— an entrepreneur and businessman. Strandlund ambitions were not the same as Wachsmann and Gropius; he focused on industrialising the production of construction components for easy assembly on-site; and thus, reduce times and increase production. Strandlund adapted a plant used to produce aeroplanes and its machinery to produce steel frames and cladding (Wolfe & Garfield, 1989:55-56; Bergdoll & Christensen, 2008:104).

The Lustron House company received over 37 million dollars loan, more than six times the General Panel Corporation. The Lustron House factory covered an area of 93,000 m^2, contained about 12 kilometres of automated conveyors, 163 presses, 11 furnaces and the probably largest porcelain enamel processor of the world by that time. Not only setting-up the factory was expensive, but its maintenance also implied high costs. Since the Lustron plant opened, it never stopped losing money, around 1 million dollars per month, counting for workforce salary, energy bills, machinery maintenance and material (Wolfe & Garfield, 1989:51,55). The following images show the scale and machinery used in the Lustron House factory (Figs. 95, 96, 97, 98, 99 & 100).

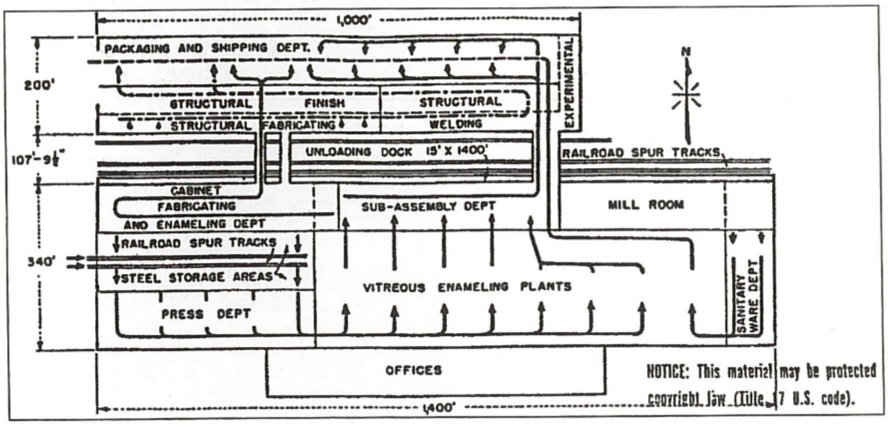


Figure 95. Lustron House factory plan (From Bergdoll & Christensen, 2008:104).

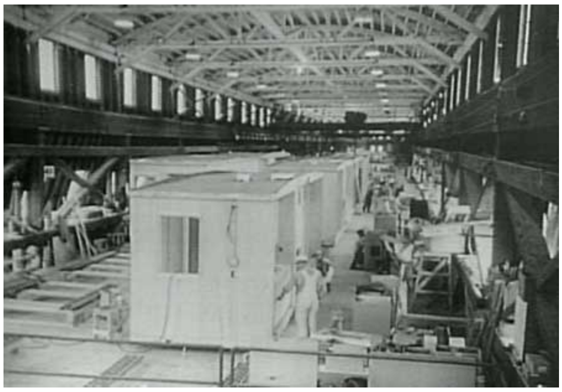



Figure 96. (left) Lustron House factory aerial view. Figure 97. (right) Finishing fabricating section of Lustron House factory.

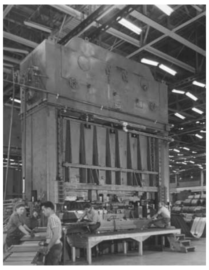
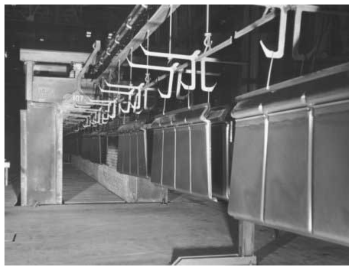




Figure 98. (left) Subassembly department of Lustron House factory. Figure 99. (middle) Press machinery of Lustron House factory. Figure 100. (right) Vitreous enamelling plant of the Lustron House factory (Photos from WOSU).

The reasons for the failure of Lustron were associated with high production costs leading to escalating prices and the insuperable difficulties in raising capital, which resulted in their incapability of paying back loans. Investment in manufacturing follows different procedures than for housing. The loans of the General Panel and

Lustron were set to manufacturing rules and expected quick production rather than an extended building process (Herbert, 1984:312-313).

Investment in traditional construction are different; these are agreed by construction milestones. Thus, in case the company gets bankrupt, lenders can take over construction and completed, that is not the case with prefabricated elements, which even close to completion, the site would only have foundations (Aitchison, 2018:89).

Investing in manufacturing is associated with potential savings in production and product market price. However, this is not always the case for housing (Goodier & Gibb, 2005:153). The General Panel houses were 15% more expensive than traditionally built houses, while the Lustron houses proved to be 30-50% more expensive than projected (Aitchison, 2018:54,90; Bergdoll & Christensen, 2008:104).

Housing peculiarities

Housing production can be compared to other industrial industries just to a certain level. Housing is a particular practice, where production systems used in other sectors might not be capable of dealing with its complexity. House buildings are attached to a unique piece of land, orientation, climatic conditions and urban form. Planning and legislation vary from site to site. Therefore, housing production requires high levels of customisation, even without considering inhabitants wants and needs (Pawley, 1971:111-112; Kendall, 2013:43; Aitchison, 2018:72; Noguchi et al., 2016a:95; Habraken, 1972:21-24,50-52).

There is a risk of emulating production processes from other industries because these can result in partial solutions, which does not incorporate a comprehensive view of the whole housing business (Aitchison, 2018:81). As an example, Wikihouse is an opensource digital manufacturing system that does not require high technological investment. It is a construction system that only contemplates the structure of the building. It has limitations as it is isolated from any geographical and climatic conditions and legislation. Similar barriers that Buckminster Fuller designs suffer, referring to the ‘Dymaxion’ and ‘Wichita’ houses. Buckminster Fuller different from the General Panel Corporation and Lustron Houses did not invest in a factory to produce the Wichita houses and was using the facilities of an aircraft manufacturer. However, mass production never started, and Buckminster Fuller’s company also went into liquidation, but the aircraft company did not (Pawley, 1990:101-114). The following images show the production of a Wichita House and its assembly (Figs. 101 & 102).

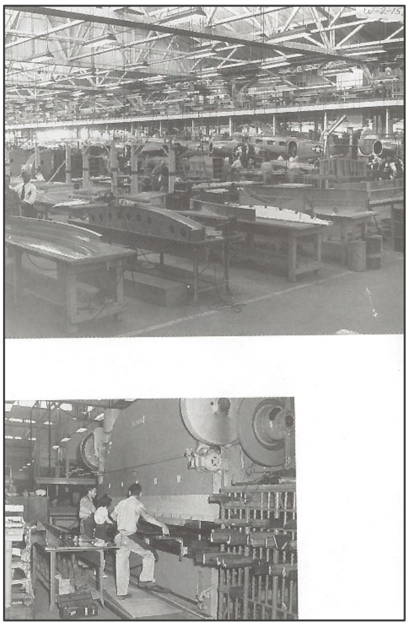
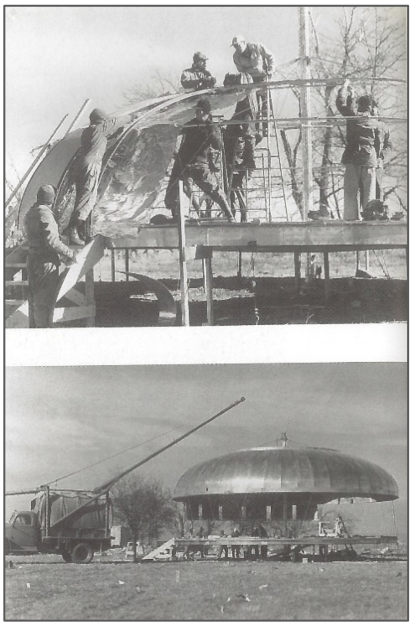



Figure 101 (left) Beech Aircraft factory (From Pawley, 1990:100). Figure 102 (right) Assembly of a Wichita house (From Pawley, 1990:106).

Manufacturing, in terms of workforce and machinery, requires stability in production to be cost-effective. However, the housing market suffers fluctuations and scaling (Aitchison, 2018:81). ‘Levitt & Sons’ housebuilding company built over 140,000 houses, by the times of the General Panel Corporation, Lustron House and Wichita house, and still active. They did not invest in manufacturing, and their construction system was based on workforce on-site using some prefabricated elements, which makes them incomparable to General Panel and Lustron in terms of the production process. However, they were able to accommodate to the fluctuating conditions of housing in the postwar USA (Rosenberg, 2019; Marshall, 2015).

Carbon Dynamic, a modular housebuilder in Scotland, went into administration in 2018 because they had cash flow problems. Earlier that year, Carbon Dynamic increase their production substantively, which causes an increase in their cash flow. Carbon Dynamic machinery is low tech and requires low investment; their financial problems were related to fluctuations in the housing market. The company was eventually sold out of administration and continues producing houses (Symon, 2018; Kemp, 2018).

Roots of mass customisation in Japanese house manufacturers

Mass customisation is a paradigm detached from any production sector (Agrawal, 2001). In theory, the implementation of mass customisation should not require investments in technology or machinery, as its focus on adjustments within the supply chains and sophistication of communication systems (Nambiar, 2009; Zhang et al., 2015: 2,7). In terms of production management, the implementation of mass customisation is highly associated with the use of lean and agile manufacturing systems, as explained in chapter 3 (Martinez et al., 2017:96; Naylor et al., 1999:97; Nahmens & Mullens, 2008:84; Naim & Gosling, 2011:343).

Historically speaking, Japanese house manufacturers (now mass customisers) implement lean manufacturing systems before reaching the high levels of customisation present today (Bock & Linner, 2015:100-114). The lean paradigm has its roots in Japanese manufacturing practices observed in the 1970s (Stone, 2012:115-116).

The Toyota Production System– a direct precursor of lean manufacturing— was developed since the 1940s. Total Quality Management, one of the pillars of the Toyota Production System, consists of sophistication of a *Jidoka* — a concept of intelligent automation developed in 1924 in the looming industry by Sakichi Toyoda, the founder of the Toyota group (Bock & Linner, 2015:100).

The other core pillar of the Toyota Production System is just-in-time manufacturing. This concept originated with the foundation of Toyota Motors by Toyoda's son Kiichiro Toyoda. The initial idea was to emulate mass production systems observed in the USA automotive industry. In the 1930s, Toyota invested in expensive machinery; however, production paused during the Second World War. After the war, there was an economic crisis in Japan, and the productivity of Toyota motors was eight times lower than the automakers of the USA. Toyota was short in capital and equipment;

thus, they research and develop techniques to increase productivity that did not require rapid investments in machinery. Toyota developed the just-in-time manufacturing system as described in chapter 3, where each production stage supplies the proceeding stages and obtains whatever needed from previous stages whenever needed; a system inspired on display and queuing of products in USA supermarkets (Sugimori et al., 1977:553; Shmula, 2017). The Toyota Production System was applied to housing production with the foundation of Toyota Housing Corporation in 1975 by Soichiro Toyoda, son of Kiichiro Toyoda (Smith, 2009:180; Bock & Linner, 2015:100; Linner & Bock, 2013:157-158).

Lean manufacturing is a common practice among house manufacturers in Japan. Lean manufacturing does not focus on providing customisation; however, it allows variability in a cost-effective manner (Nahmens & Mullens, 2008:97). Prefabrication does not necessarily imply either mass production or standardisation (Davies, 2005:205). Japanese house manufacturers meet the requirements of mass customisation, where lean manufacturing systems accommodate the house manufacturers' demand-oriented business (Bock & Linner, 2015:222).

In the 1950s and 1960s, Japanese house manufacturers oriented their business on mass production, as explained in chapter 4 (Yashiro, 2014:19-21; Aitchison, 2018:93; Yamada, 1999:106). However, once the housing shortage came to an end in the 1970s, the Japanese housing needs changed. House buyers began to express clear signs of disapproving of or disliking monotonous mass-produced houses (Yashiro, 2014:24, Johnson, 2007:15). The Japanese government promoted the improvement of prefabricated housing with funding and research, like the ‘Parts for Housing Facilities and Standardization’ research in 1970.

Consequently, the construction industry was pushed to adopt an ‘open system’, where the housing components and parts were built separately but made compatible to other parts, as explained in chapter 4 (Ryu, 1982:121). Japanese manufacturers of factory-made components supply a wide variety of products. In the 1970s, Japanese manufacturers of aluminium window sashes had over 20,000 products while manufacturers in the USA had fewer than 1,000.

Therefore, since the 1970s, individual customisation became a critical issue for suppliers of industrialised buildings. Japanese house manufacturers modify their business to a customer-oriented approach by implementing agile manufacturing systems. With the growing demand for adaptation to individual requirements, Japanese house manufacturers found value creation on the use of lean and agile manufacturing systems and collaboration with factory-made-components manufacturers, which eventually led to mass customisation.

Housebuilders that implement mass customisation systems and business had an increase in sales from the 1970s (Yashiro, 2014:25-26). The following image shows the sales of prefabricated houses from 1961 to 2001 by material of construction. It presents how from 1961 all prefabricated systems increase; then, in 1973, following the oil crisis, the numbers of prefabricated dwellings made by precast concrete and prefabricated timber structure dropped sharply. It also shows how the number of prefabricated timber and steel structure dwellings steadily increased again from 1976 to 1996, due to the promotion of mass customisation; where precast concrete production systems inflexibility made it unable to respond to diversifying needs (Fig. 103).

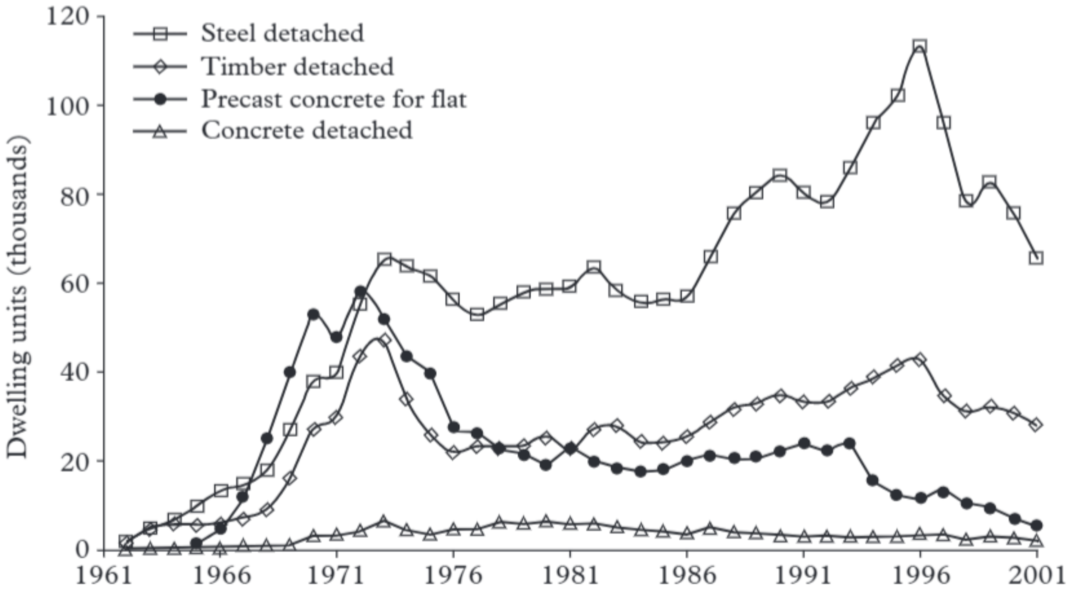


Figure 103. Number of prefabricated houses sold in Japan between 1960 and 2001 by the material of structure (From Yashiro, 2014:25— Figure 4; originally sourced from Sold Prefabricated Houses Statistics shown in Japan Prefabricated Construction Suppliers and Manufacturers Association, 2003).

Sekisui House and Daiwa House, the two largest house manufacturers in Japan, sharply increased from the mid-1980s to the mid-1990s; the decade in which they introduced lean and agile manufacturing and promoted mass customisation (Yashiro, 2014:25-26; Naim & Barlow, 2003:593).

As seen, the investment of the industrial capacity of Japanese house manufacturers is more related to their volume, long history and link to other manufacturing industries, than to the implementation of mass customisation. The implementation of lean and agile manufacturing systems has had a substantial weight on the development of mass customisation in Japan.

Nahmens & Mullens (2009:97-98) propose the following guidelines for implementing lean manufacturing for housebuilders that want to maximise product choice in their business, none of which directly imply high investments in industrial machinery or technology.

- *Move activities affected by customisation off the main production line*— Develop off-line parallel processes that are synchronised to mainline flow, delivering sub-assemblies on a just-in-time basis. It reduces the mainline cycle time and disconnects the mainline from any cycle time variability due to product choice.

- *Improve and standardise activities that are affected by product choice*— Develop common methods, equipment and tools that simultaneously are highly efficient, assure quality, and minimise process cycle time variation due to product choice.

- *Move equipment and materials closer together*— Utilise straightforward flows, which reduces travel time, congestion delay, and related damage. It reduces the variability of cycle time associated with the number of trips or movements to get material for different product configurations.

- *Use continuous flow systems whenever reasonable*— Utilise limited queues with pulling just-in-time techniques to drive production; and consider pulling materials in built-to-order kits and code materials, instead of unique part numbers. This strategy controls inventories and insures sub-assembly availability, even as product choice increases.

However, having lean manufacturing systems does not mean mass customisation. Aspects of communication, involvement of customer into the design/production process, marketing orientation and ability of correctly interpret customer needs and infuse them into the product space are crucial for the implementation of mass customisation (Salvador et al., 2019:1; Piller et al., 2004:435; Jiao & Tseng, 2004:745; Wang et al., 2017:313).

Importance of market-orientation in mass customisation and energy efficiency

As explained in chapter 3, mass customisation is a concept in which marketing is the core aspect. Thus, the driver for implementing mass customisation should come from the market, rather than from the production capabilities of the firm. Modular production, flexible automation, a flexible workforce and effective navigation toolkits are important business model elements to successfully operate in mass customisation markets. These elements, however, represent only one perspective on a successful business model. In mass customisation, the sale is not the end of the marketing process but the beginning of a relationship among customer and producer, which includes design, production and marketing processes. Effectiveness is contingent on the company’s market orientation, including its ability to correctly interpret customer needs and infuse them into the solution space. Market orientation increases the effect of modular production, effective customer navigation toolkits, and flexible automation on the manufacturer's probability of survival over a long-time horizon (Bardakci & Whitelock, 2003:464; Salvador et al., 2019:1; Boër et al., 2018:247-248).

Mass customisation requires customer input into the design process. Consumers left to their criteria can make choices by intuition that would not satisfy their wants and needs. Good practice, including sustainable features, could be undervalued and ignored if consumers cannot identify cost-efficiency and life-style benefits (Johnson et al., 2013:5). Consumers must have some idea as to what they want from the product. Thus, producers need to invest in specifying the products and providing advice to their customers to make optimum use of their solution space (Bardakci & Whitelock, 2003:479). As Davies (2005:205) states,

> *'Offering customer a choice is one thing; asking them to design the whole building from scratch quite another.'*

Customers often have trouble deciding what they want and then communicating or acting their decisions; thus, setting an appropriate market-orientation requires sophisticated marketing strategies to extract information from the consumer to deduce their wants and needs, as *'to make something unique requires unique information'* (Zipkin, 2001:82,86).

The decision-making process can follow a rational choice based on an evaluation of costs against benefits. However, customers can also utilise their emotional perspective and may choose to either ally or distance themselves to features they like or dislike

(Faiers et al., 2007:4386). People commonly deviate from the rational choice, in which they objectively weigh up the costs and benefits of all alternatives before choosing the optimal option. Consumer choices and behaviour are, to a large extent, driven by cognitive biases, heuristics, and other predictably irrational tendencies. 50-90% of oh households favour energy from renewable sources, even at a premium price; yet, those preferences do not translate into practice. In the UK, only 1% of the population are actual users of renewable energy (Momsen & Stoerk, 2014:376). It is important for producers to take these phenomena into account when developing marketing strategies, not only to encourage renewable and sustainable energy use but to ensure cost-effectiveness and maximise return on investment (Frederiks et al., 2015:1385,1391).

House buyers understand information related to lifestyle and daily activities, such as improved well-being, *doing-their-bit* for the environment, or warm, bright or quiet space. Metrics used to discuss energy consumption, carbon emission and construction quality, such as U-Value or kWh/(m²a) of primary energy might be meaningless (Jefferson & Sellwood, 2010:6-7). Customers value on energy-efficient dwellings is primarily perceived as benefits in health and wellbeing, following by long-term cost and environmental impact (Berry et al., 2019:450-451; Hale, 2018:15)

Japanese house manufacturers invest a significant amount of their resources in marketing. As an example, marketing and management costs of Sekisui House represent on average 25% of their expenses, where only 3% goes for advertisement (Gann, 1996:446). A significant proportion of these costs involve maintaining their show houses and information centres. It is estimated that one show house costs around £400,000 to maintain annually, including the salaries of on-site staff. These costs are further increased as show-houses are replaced with newer models every four years. House manufacturers spread their housing parks, show houses and information centres around the country, each with slight variations to adapt to each context (Johnson, 2007:17; Noguchi et al., 2016b:347). Housing parks are places where 20 to 40 companies display their show houses. Some companies have private housing parks where they display different of their models. These housing parks not only display the models but serve for educational purposes where salesmen explain the potential features of the houses and the quality of their products through live experience (Davies, 2005:191; Aitchison, 2018:116). The following images show a Housing Park and showhouse (Figs. 104 & 105).

Figure 104. (left) Senri Housing Park in Osaka, Japan (From Davies, 2005:192). Figure 105. (right) Sekisui House show house with timber structure (From Aitchison, 2018:117— Figure L.3).

The housing information centres consists of buildings with exhibitions, material samples and showrooms. The information centres are curated as museums where staff guide visitors and explain the history of the company, show certificates and examples of previous projects, highlight their social and environmental commitments. They also display scale one-to-one prototypes or show the assembly of full houses to generate and increase the customers' trust to the company (Davies, 2005:189-191; Aitchison, 2018:96). The following images show a display and prototyping lab (Fig. 106 & 107).

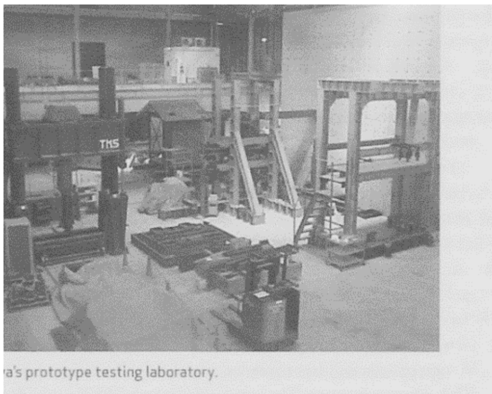


Figure 106. (left) Display of Misawa history in Misawa's House information centre at Nogaya, Japan (From Aitchison, 2018:116— Figure L.2). (right) Figure 107. Daiwa's prototype testing laboratory (From Davies, 2005:190).

The information centres show customers and visitors how the houses are constructed, structured and about the meaning of all the different features available (Noguchi et al., 2016b:350-351; Aitchison, 2018:116-117). The following images present a show house, and information centre of Sekisui House— the largest mass customiser in Japan recognised for its high levels of investment in showhouses and information centres (Figs. 108 & 109).

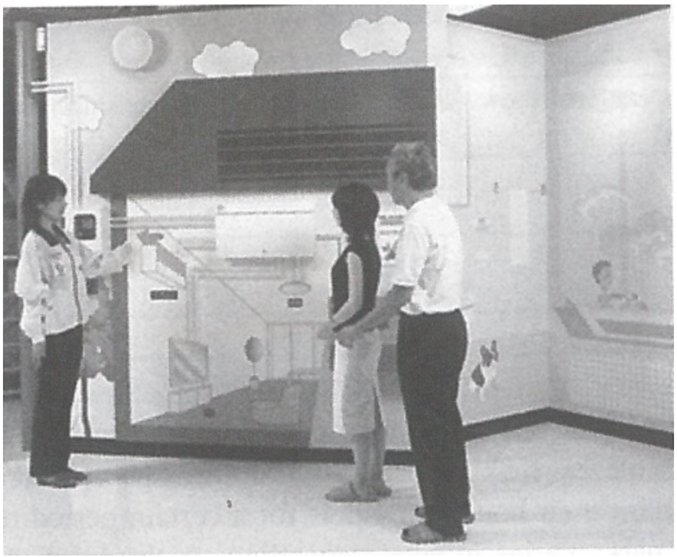


Figure 108. (left) Sekisui House advisory board (From Noguchi et al., 2016b:350— Figure 12.4). Figure 109. (right) Sekisui House information centre display of energy cells environmental systems (From Aitchison, 2018:116— Figure L.2).

Japanese mass customisers use visual information, interactive models and samples, catalogues, reviews of previous customers, visits to facilities and individual design consultations to increase customer's understanding; and thus, provoke informed choices that cover their solution space and promote the consumption of energy-efficient features. The information centres also serve as sales points. Customers are invited to test parts of the housing system, including aspects of usability and accessibility; their preferences and measurements are recorded and input into the design of their houses (Bock & Linner, 2015:123). The information centres also function as design consultation bases, where salesmen (usually architects) assist in the selection of architectural designs, including the customisation of plans, selection of materials and additional features. They use advanced information and communication technologies to render and display the characteristics of the house; not only in visual appearance but in costs and performance (Noguchi et al., 2016b:350). The following images show how customers interact with housing part samples and how their choices are displayed (Figs. 110 & 111).

Figure 110. (left) Sekisui House information centres' example of one-to-one configurators (From Bock & Linner, 2015:124— Figure 5.12). Figure 111. (right) Sekisui House custom design demonstration at an information centre (From Noguchi et al., 2016b:350— Figure 12.5).

Japanese mass customisers use their showhouses and information centres as an integral part of the design process, where customers can make design-decisions based on aspects related to life experience and visualisations, rather than construction plans and engineering metrics.

They also use information centres for research purposes to redefine their marketing and market orientation. The feedback and information collected from customers and visitors are analysed and used to redesign production lines and business strategies.

Chapter 6 describes the production process of house manufacturers in the UK and mass customisers in Japan selected as study cases and explored through material collected from fieldwork. Chapter 7 presents a description of the design and marketing strategies used by the study cases.

Summarising table

This chapter described the speculative housebuilders in the UK and Japanese mass customisers housing models and procurement processes. Both procurement and selling processes are contrasting among each other. The following table resumes these differences (Table 18).

Table 18. Comparison of housing models, production processes and manufacturing capacities between UK speculative developers and Japanese mass customisers.

	UK ***Speculative housing***	**Japan** ***Mass Customisers***
Housing model	- Based on land control and speculation - Mass housing or push model	- Customers require a plot of land - Customers are involved in the design decision-making process of the houses - Business competition on service and quality
Procurement process	- Final customers are segregated from the selling process - Involves multiple agents: housing developers, contractors, manufacturers and sub-manufacturers - Includes land banking - Manufacturers do not interact with end-user - Most of the construction process happens on-site	- The production only starts when the customer places an order - Design, production and marketing are usually managed by a single company - Implicit interaction between manufacturer and final user - Most of the construction process happens off-site
Manufacturing capacity	- Manufacturers work as suppliers to contractors and housebuilders - Production determined by housebuilders project	- Integral to housebuilders - Highly industrialised - Automated - Use of robotics - Production determined by the final customer's choice

As observed, the housing procurement process in the UK is centred on land development. Accordingly, construction systems, housing procurement and selling processes follow and run in accordance to what land speculation dictates. Thus, the design and construction processes start before the involvement of the final customer and customisation processes are not present, or only to a superficial final detailing.

In contrast, Japanese house manufacturers housing model is exclusive to customers with individual plots of land. Thus, the production of a house cannot start without the involvement of the customer. Furthermore, the manufacturing capacity of Japanese housebuilders is highly industrialised and automated; where some Japanese house manufacturers even use robots in their manufacturing and assembling processes. The characteristics of the Japanese and UK manufacturing contexts differ, not only in their capacity and sophistication but in their role in the design and procurement processes. The UK manufacturers work as suppliers to contractors and housebuilders, while Japanese manufacturing follows the design choices of the final customer.

Conclusion

This chapter describes the procurement and selling processes of the UK housing developers and Japanese mass customisers to point out the differences that could make the adoption of Japanese models unappropriated to the UK.

This chapter links to chapter 4, as most of the differences among both contexts are consequences of the socio-economic and cultural contexts. For Japanese mass customisers, high industrial capacity is a result of its particular historical and contextual characteristics. In certain times, the Japanese housing need was extremely high and industrial power was used to reach the needed production volume. Today, this housing need has been reduced. Housebuilders mass customise to extend their market coverage and achieve the production volume that corresponds to their manufacturing capacity and remain profitable. Japanese house manufacturers spinoff from manufacturing companies and has developed slowly, modifying with time to the values expected from house owners. As a result, the development of mass customisation in Japanese house manufacturers is independent of the adoption of machinery and technology. The levels of mass customisation observed in Japan are due to the use of lean and agile manufacturing systems, which are not strictly attached to investments in industrial machinery.

For house developers in the UK land is the main asset. They invest, and had invested, in acquiring land as the UK possess land banks for urban development, different from the Japanese situation. Accordingly, the procurement and selling processes are designed around it. However, extensive land control by house developers has resulted in low competition and monopolised markets, where quality and customer involvement are diminished. Housing associations and small/medium scale housing manufacturers and developers are approaching off-site manufacturing as a strategy to compete in the housing market; while top house developers are allowing customers to personalise finishing details to sales and customer satisfaction levels.

The attraction to investing in manufacturing in the UK, in addition to the support of governmental entities to Modern Methods of Construction, imply risks not present in the Japanese scenario due to the difference of historic and land development conditions. Moreover, if housebuilders in the UK expect to achieve mass customisation, it is important to notice that Japanese investments in industrialisation were developed to achieve volume, not customisation. Japanese major investments towards mass customisation have been placed in marketing and selling infrastructure, including showhouses, information centres and selling centres. Thus, investments towards the implementation of mass customisation in the UK should focus on sophisticating marketing and selling infrastructure and strategies.

This chapter also explains the risks of investing in manufacturing capacity using some historic examples of housing companies that bankrupt due the mismatching of the virtues of industrial manufacturing with their housing ambitions. It can be resumed that the reasons for these housing companies to fail came from psychological and cultural bias, high cost and finance barriers, or a misunderstanding of the housing peculiarities.

There are important lessons that can be learned from the historic attempts to approach housing from an industrialised perspective. First, houses are different from other products, like cars or shoes. Housing production is more complex than other practices and requires the intervention of multiple agents. Houses' designs need to adapt to the environment; and thus, single design productions are inadequate for mass production. Second, unbalanced approaches usually fail to produce houses that accommodates to the housing markets. Engineering or architecturally oriented designs tend to result in houses that cost over the market prices and are not consumed. Actually, it is common that industrialised houses cost around 15% more than the average housing markets; current examples are Huf Haus in Germany and Sekisui House in Japan. Third, understand the market. Huf Haus and Sekisui House understood that their market niche was the high-end market (luxury). Thus, their houses are designed to fulfil the quality standards of that particular market niche. Also, their production capacity was planned for a lower scope rather than economies of scale. Fourth, that the housing market is volatile and difficult to predict. Industrial production, especially mass production, benefits from constant consumption. The main goal of investing in machinery is that your products get consumed constantly to the maximum of the capacity. Hence, payback times can be ensured, and facilities and workforce are efficiently used. However, the housing market hardly behaves this way. It is important to plan investments gradually and to study housing markets in advance. Fifth, that industrial production is before anything a business and needs to be profitable. Different to housing estates, or the Prefabs, produced by governments, the industrialisation of houses are private ventures that depend on their financial success. Council estates are economic investments towards the improvement of social conditions, not economic. The investment for houses produced by bespoke architects or contractors comes directly from the client; therefore, designers are exposed to low risk. Therefore, development of industrialised housing has to focus always on providing financial growth or stability.

The following chapters describe the Japanese and UK house manufacturing scenario through the description of selected companies to compare the current state of both scenarios and visualise the implementation of mass customisation in the UK from the particularities of the study cases.

Chapter 6

Back of House: manufacturing capacity and processes

This chapter consists of a description of the production processes of selected Japanese mass customisers and UK house manufacturers through information, data and material collected in the fieldwork. This chapter aims to analyse if the UK manufacturing industry possesses a robust capacity to implement mass customisation. It analyses three Japanese mass customisers and three UK manufacturers involved in housebuilding. It explains how these companies are using lean and agile systems to produce variable outcomes. This chapter concludes by identifying the factors that make UK manufacturing companies suitable for mass customisation.

Introduction

As explained in chapter 3, the implementation of mass customisation requires three capabilities— solution space, robust process and choice navigation (Piller & Tseng, 2010:4). Robust process refers to the company's capability to produce a flexible outcome in an efficient manner (Hart, 1995:36). Japanese mass customisers achieve variability and efficiency using lean and agile manufacturing systems, as explained in chapters 3 and 5 (Stone, 2012:121; Nahmens, 2007:33; Nahmens & Mullens, 2008:83; Gupta & Jain, 2013:245).

However, the implementation of the Japanese manufacturing capacity and technology is not feasible to the UK context. There are multiple risks and barriers that prove that investing in manufacturing capacity and technology would endanger the survival of housebuilding companies, as explained in chapter 5 (Salvador et al., 2019:1; Herbert, 1984:309; Davies, 2005:24).

The UK contextual situation, land availability, housing need, production volume, housing business models and procurement process are very different from the observed in Japan (Barlow et al., 2003; Barlow & Ozaki, 2001; Barlow & Ozaki, 2005). The highly industrialised robust process observed in the Japanese housing sector is a result of the drastic industrial growth and housing deficit that Japan had after the Second World War until the 1990s, as explained in chapters 4 and 5 (Johnson, 2007; Buntrock, 2017).

The UK housing industry might have the manufacturing capacity to implement mass customisation. This chapter presents the analysis of the production capacity and procedures of three manufacturers in the UK, to identify if they have the potential, or in any case, already use lean and agile robust processes.

Selection of companies

The companies selected for comparing production capacity and production process were Sekisui House and Sekisui Heim from Japan; and Robertson, Scotframe and Carbon Dynamic from the UK.

Sekisui House (Japan)

Sekisui House was selected because of its scale, volume and high sales of zero energy houses.

Sekisui House is the largest and one of the most well-known Japanese mass customisers. It was established in 1960 from the housing division of Sekisui Chemical Corporation. Sekisui House uses high levels of factory automation in their production. In 2017, its revenue accounted for over 14,000 million pounds and sold 13,600 houses. It had cumulative sales of over 2,380,000 houses in 2017, the largest worldwide, which would count for 8% of the total housing stock in the UK (Aitchison, 2018:115-116; Noguchi et al., 2016b:357-359; Bock & Linner, 2015:149-152; Barlow et al., 2003:137-140).

Sekisui House has also compromised to use 100% of renewable energy by 2040 with an intern goal of 50% by 2030, and all the waste material is recycled (Sekisui House, 2018:4,14,28).

Customisable detached houses only account for 17.2% of their business, which covers a wide range of sectors related to housing, including rental housing, remodelling, urban development, vertical housing, housing development and real estate management (Sekisui House, 2018:4). The following graphic shows Sekisui's House business distribution (Fig. 112)

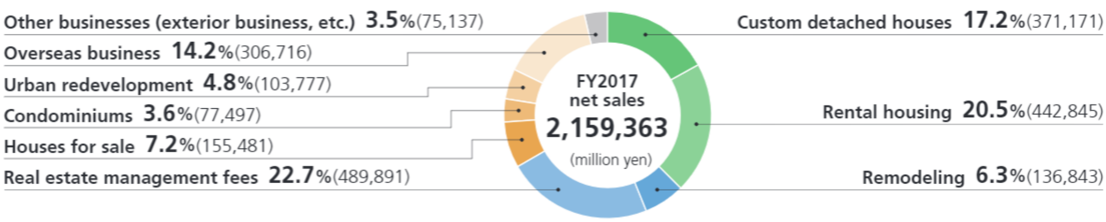


Figure 112. Sekisui's House business 2017 distribution (From Sekisui House, 2018:4).

Sekisui Heim: Sekisui Chemical (Japan)

Sekisui Heim was selected because, different from Sekisui House, it uses modular construction systems and still provides high levels of customisation. Sekisui Heim provides higher levels of customisation than other companies that also use modular construction systems, as Toyota (Barlow et al., 2003:138-140).

Sekisui Heim is officially registered as Sekisui Chemical Corporation and is the company where Sekisui House originated from in 1960; Sekisui Heim did not produce houses until 1971. Sekisui Heim focuses on the production of high performance and value-added housing products. They use modular construction systems to ensure high levels of in-factory completeness, where 80% of the housing process is completed off-site (Bock & Linner, 2015:190; Furuse & Katano, 2006:352).

Housing business provides 36% of their profit, which includes detached customisable houses, condominiums, remodelling and real estate (Sekisui Chemical, 2018:31-33). The following graphic illustrates Sekisui's Chemical business distribution (Fig. 113).

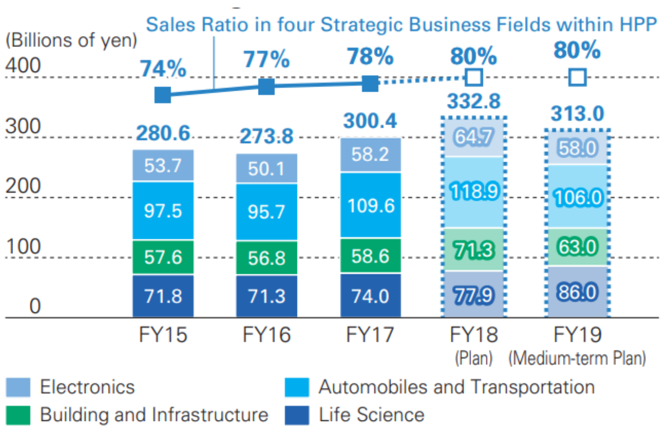


Figure 113. Sekisui's Chemical business distribution from 2015 to 2017 and planned for 2018 and 2019 (From Sekisui Chemical, 2018:32).

Robertson (UK)

Robertson Group was selected because it is a company that covers housing development, working contractor and manufacturer, with emphasis on using prefabricated timber frame construction.

Robertson Group was founded in 1966 as a joinery family company. Robertson Group is the 30th ranked company by turnover and 16th by profit; and one of the largest independently owned construction company in the UK (Construction Company Directory, 2019). Robertson Group is subdivided in different businesses; where Robertson Construction, Robertson Timber Engineering, Robertson Property and Robertson Homes are related to housing development. Robertson has produced timber products for housing construction since 1986 and registered as Robertson Timber Engineering in 1996.

Robertson has built projects focused on the improvement of operational efficiency for over ten years, achieving BREAM and other certificates; however, these are usually not in housing projects.

Robertson Timber Engineering has the capacity to produce a variability of products, including timber panel walls (open and closed), floor cassettes and timber frame roofs. Robertson does not possess a mass customisation system. Robertson subdivision of business caused the isolation of manufacturing from the housing development business. Robertson Group and Robertson Residential are registered as separate but are promoted as a single company. Robertson Timber Engineering produce for

Robertson Residential Group but does not have an input on the design, neither contact with final users. The following image shows the legal arrangement and division of the Robertson Group (Fig. 114).

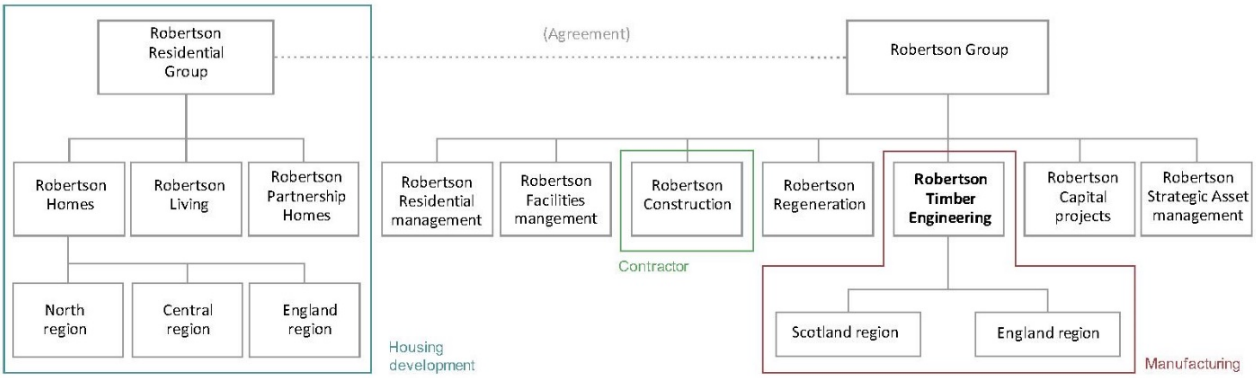


Figure 114. Robertson Group legal arrangement and distribution (From Murphy interview, 2018).

Scotframe (UK)

Scotframe was selected because it is a manufacturing company focused on the production of timber frame panels that provide self-builders standardised but customisable products, including a construction kit to assemble the structure of a house, windows, doors, insulation, stairs and internal and external finishes.

Scotframe was founded in 1989. It has accumulative sales of 30,000 houses. Their business focuses on providing construction packages for contractors and self-builders. As contractors' suppliers, their business model is similar to Robertson Timber Engineering. Working for self-builders, Scotframe offers packaged construction kits of pre-designed detached houses that can be customised in terms of insulation thickness and quality and aesthetic features. Scotframe also works with bespoke projects.

Scotframe has developed on-factory insulation techniques, which claim to provide 40% better thermal performance and reduction of 10% CO_2 emissions than the average new houses in the UK.

Carbon Dynamic (UK)

Carbon Dynamic was selected because it is a housing company that work on-demand (bespoke) delivering prefabricated modular dwellings using low manufacturing technology. Carbon Dynamic is capable of producing a variable outcome with low industrial and technological equipment.

Carbon dynamic was incorporated as a company in 2011 as an independent housebuilder. It went into administration in 2018 due to cash flow issues, as explained in chapter 5. Later in 2018, it was purchased by Pat Munro, a contractor company based in Scotland founded in 1945, with business in construction, quarry extraction and manufacturing, and property development. At the time of writing, Carbon Dynamic is active and kept their business focused on self-builders and bespoke projects (Kemp, 2018; Taylor, 2018).

Carbon Dynamic modular construction system results in high levels of airtightness. Its dwellings consume 7% less energy than the average house in the UK. Carbon Dynamic outsource timber panels and other components specified to their projects, avoiding storage, waste and the need for equipment.

The Japanese scenario

Sekisui House

Manufacturing capacity

Sekisui House possesses five manufacturing plants spread across the Japanese territory. Their capacity and scale are described as follows.

- (1) *Kanto Factory*— Opened in 1970 with an area of 309,500 m^2. It can produce over 870 dwellings per month, which means over 10,000 per year.

- (2) *Shizuoka Factory*— Opened in 1980 with an area of 246,000 m^2, where 124,300 m^2 are destinated to manufacturing purposes. It has the capacity to produce 800 dwellings per month.

- (3) *Yamaguchi Factory*— Opened in 1973 with an area of 224,900 m^2. It has a maximum capacity of 450 dwellings per month.

- (4) *Hyogo Factory*— Opened in 1985 with an area of 59,000 m^2. It manufactures components and feeds the other plants. Its capacity cannot be measured in houses.

- (5) *Tohoku Factory*— Opened in 1997 with an area of 121,500 m^2. It has a maximum capacity of 300 dwellings per month.

The following images represent the Sekisui House factories, with an aerial view a plan and a representative image. In the plan, the blue areas represent the manufacturing facilities, pink storage, green office and inspection yards, magenta welfare facilities, grey parking space and residual spaces, while brown represents the information centres and selling points, which are described in chapter 7 (Fig. 115).

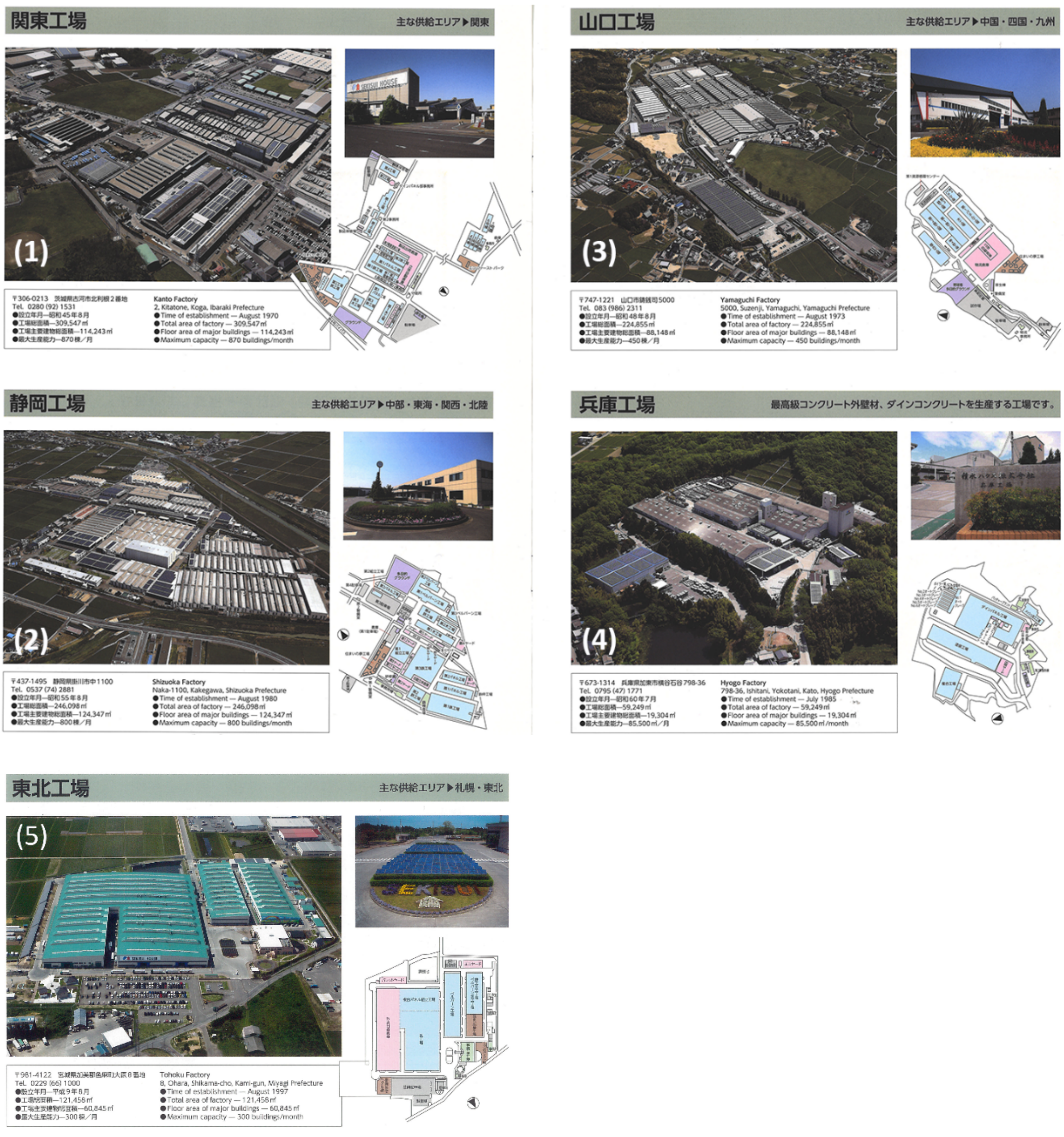


Figure 115. Factories of Sekisui House (From material collected in the visit to Sekisui House in May 2017).

Production process

Sekisui House construction systems consist of a panelised kit of preassembled steel panels and timber frame houses. Some stages of their production line are entirely operated by robots. More than 40% of the work remains on-site, taking about 2 to 3 months.

Sekisui House uses a flow line-like and group-like manufacturing layout organisation. Its production process is staged in six main steps. It starts from (1) ordering the materials and (2) procure them into useful elements. Then, (3) the production stages take place, including on-site manufacturing and assembling. Then, (4) the assembled panels are delivered to site and (5) construction on-site takes place. Finally, (6) waste materials are collected and recycled. The following diagram shows the sequence of Sekisui House's production (Fig. 116).

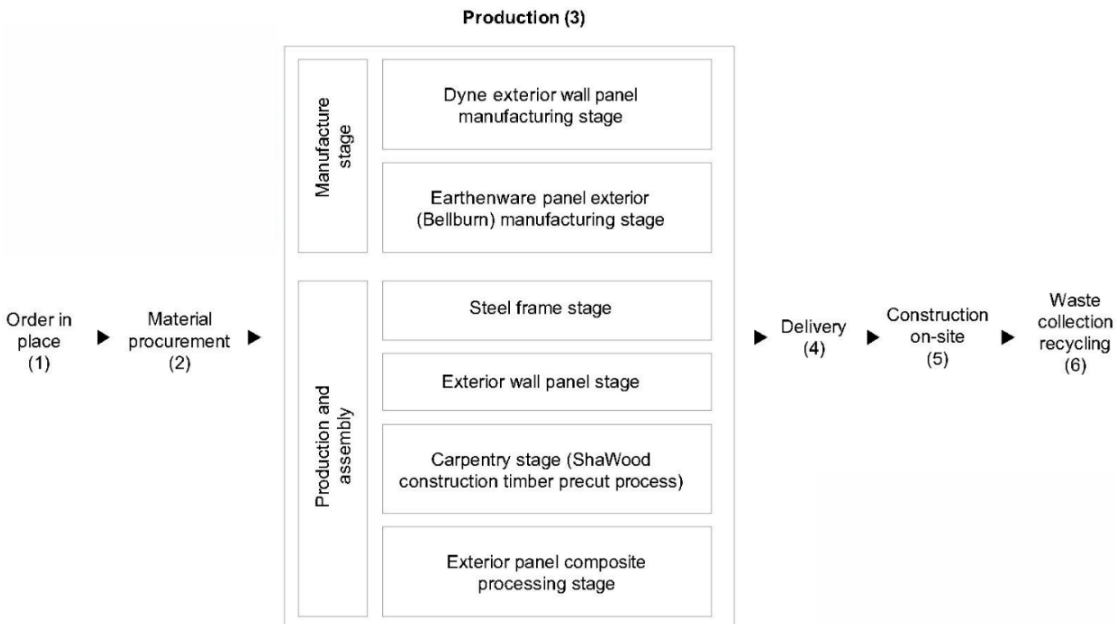


Figure 116. Sekisui House production stages (From material collected in the visit to Sekisui House in May 2017).

Sekisui House produces a large number of components, most of them from raw material. For example, for external cladding, Sekisui House produces concrete and ceramic panels from scratch; where each of them requires a different manufacturing line and machinery.

The concrete wall-panelling are produced as follows. First, (1) the concrete is poured into moulds by controlled machine. Once the concrete dries enough, (2) the concrete panels are removed from the moulds. Then, (3) the panels get secondary curing. The panels are cured for around 20 hours in completely hermetically sealed steel tanks at high temperature and high pressure. The following images illustrate the concrete wall-panelling process of Sekisui House (Fig. 117).

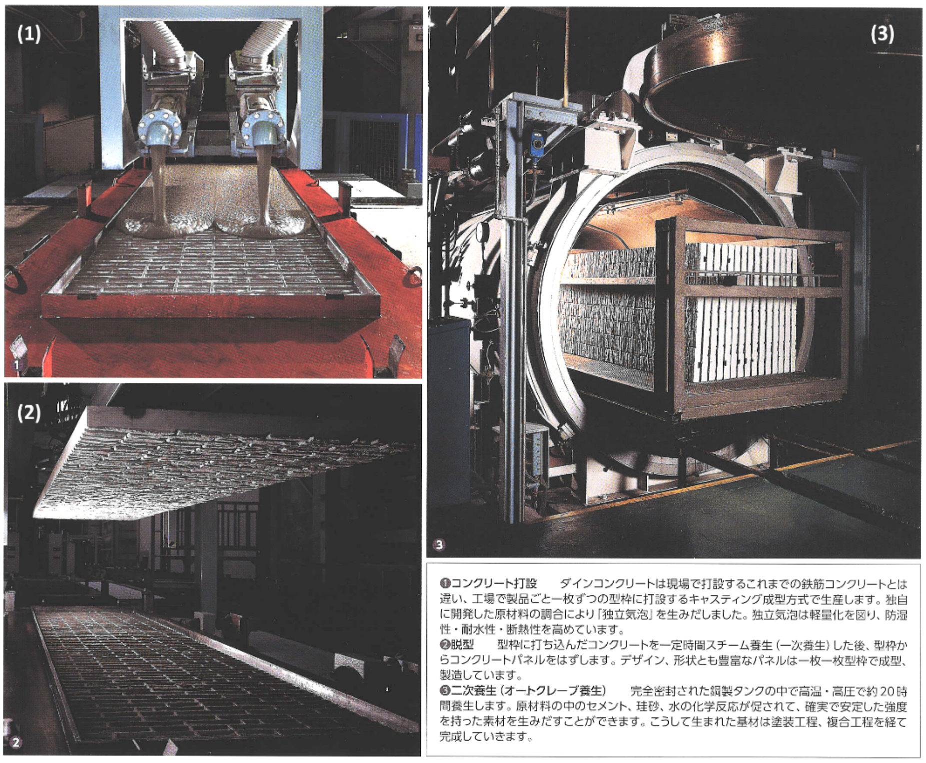


Figure 117. Sekisui House's concrete wall-panelling production (From material collected in the visit to Sekisui House in May 2017).

Sekisui House has developed a material mixture that produces air bubbles in the concrete, which makes it lighter than reinforced concrete. The second curating process encourages chemical reactions between the cement, silica sand, and water in the raw material, and allows the creation of a material with robust and reliable strength. The moulds are selected for each house, not only in lengths and form but in finishing style. The following image shows the scale of the sealed tank in the Kanto factory (Fig. 118).

Figure 118. Sealed tank for Concrete panels in Kanto Factory of Sekisui House (Photo by Author in fieldwork to Sekisui House in May 2017).

The ceramic wall-panelling production is different from the concrete. First, (1) more than ten different raw materials are mixed and kneaded into a paste. Then, (2) the paste is shaped using moulds. (3) The shape base material is dried, and a glaze is applied to the surface. (4) The panels are then fired consecutively in a furnace. Then, glass fibre is affixed to the back of the ceramic panels to reinforce them. Finally, (5) the panels are measured with a laser to identify the precise measurement and colour and stock these in their correspondent batch. The following images illustrate the ceramic wall-panelling process of Sekisui House (Fig. 119).

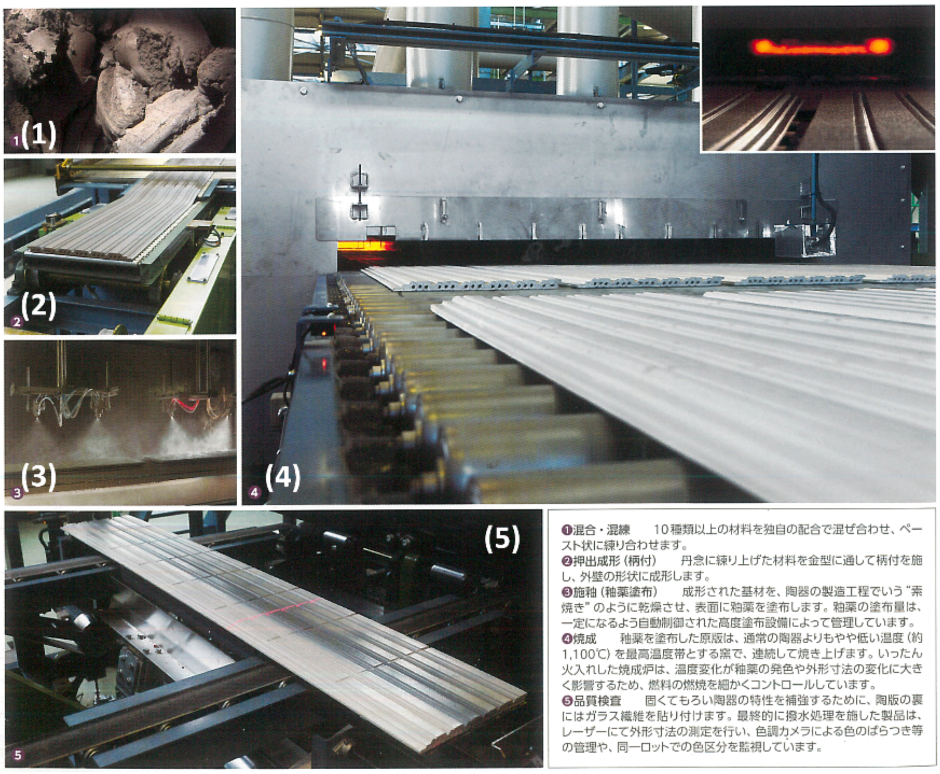


Figure 119. Sekisui House's ceramic wall-panelling production (From material collected in the visit to Sekisui House in May 2017).

The ceramic and concrete walls have different patterns, resistance to fire and scratches, and thermal qualities. The customers select their desired exterior cladding depending on their needs and budget.

These wall panels are then attached to a frame, which shapes the construction panels. Sekisui House can produce steel or wood frames. Accordingly, the production of these follows a different manufacturing process.

The steel framing process is highly automated, uses robots and do not require any human operator. The steel frame manufacturing can run 24 hours, and manufacturing results are very precise. First, (1) the materials are cut, drilled and organised. Then, (2) robotic arms weld the steel parts to form the frames. Finally, (3) the frames are sunk into the coating material. The following images illustrate the steel framing process of Sekisui House (Fig. 121)

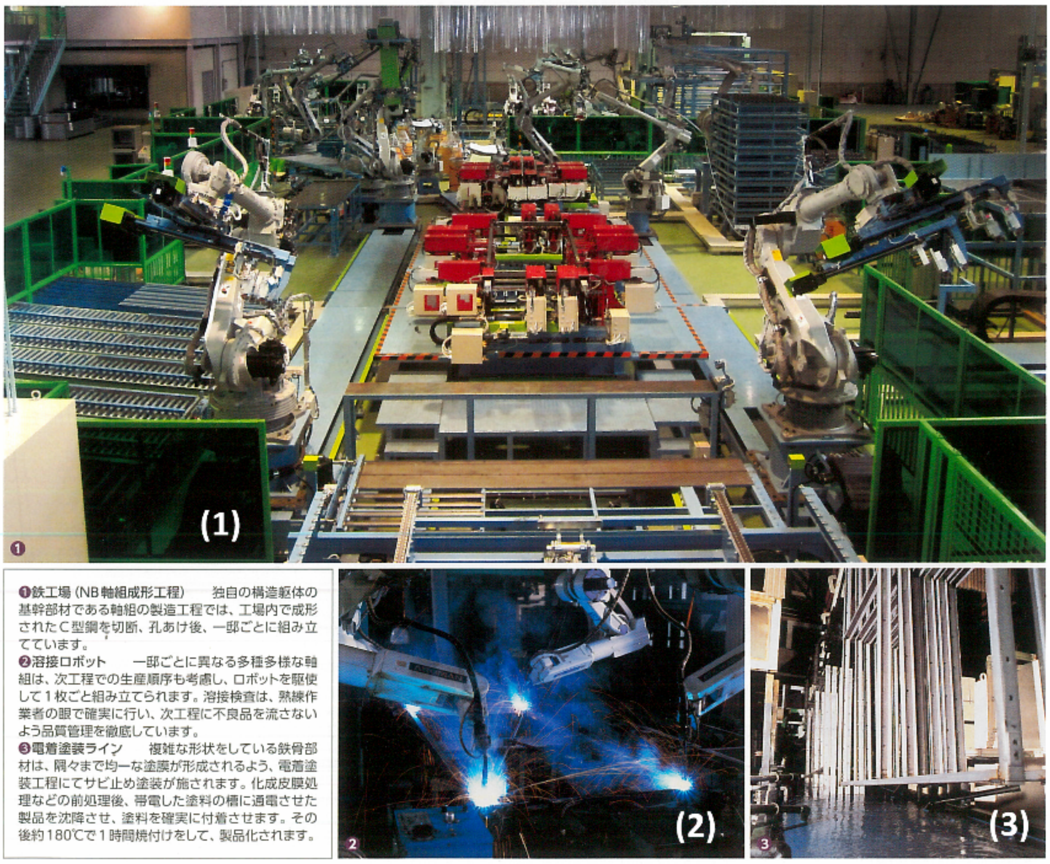


Figure 120. Sekisui House’s steel frame production (From material collected in the visit to Sekisui House in May 2017).

Sekisui House also has a production process for wooden frames and assembly facilities to fit the ceramic and concrete panels into the structural frames. Sekisui House also has facilities in charge of managing the construction logistics, including delivery, coordination with suppliers, construction and supervision.

Sekisui House dwellings are usually equipped and include furniture, all of which are supplied to the site. Finally, Sekisui House factories have resource circulation centres to recycle and treat waste materials, which include construction waste.

Additional production processes and capacity

The factories of Sekisui House have solar power field to power their machinery. The photovoltaic panels are located on the plant roofs and residual spaces. The following images show solar panels in the Tohoku and Kanto plants (Figs. 122 & 123).

Figure 121. (left) Solar panels used as decoration in Tohoku plant (From material collected in the visit to Sekisui House in May 2017). Figure 122. (right) Solar panels used to power recycling facilities in Kanto plant (Photo by Norrie Smith in the visit to Sekisui House in May 2017).

Sekisui House possesses large recycling facilities adjacent to or in their factories. Manufacturing waste is highly taxed in Japan. 100% of the waste is recycled in all Sekisui factories since 2002. The recycling facilities also treat waste from offices and information centres (Sekisui House, 2018:13).

Recycling is considered part of their supply chains and production process. Thus, they apply lean systems to the recycling process. The recycling plants are highly organised, tasks are represented with visual aids as a technique to make the recycling process more efficient and avoid workers mistakes. Visual signs are used to allow workers to identify where and how to store the material, as they deal with thousands of materials. The following images show the visual aids at the recycling centre of the Kanto factory (Fig. 123).

Figure 123. Visual signs in Sekisui House Kanto recycled facilities (Photo by Author in the visit to Sekisui House in May 2017).

Visual signs also assist workers in the process. Sekisui House workers are trained to disassemble a tatami matt in seven minutes, separating and arranging all the materials collected. The following images show the disassembling of a tatami matt by a single worker. It is observed that in the back, there is a graphic showing the disassembling process step by step, as instructions (Figs. 124, 125 & 126).

Figure 124. Disassembling process (Screenshots of video by Norrie Smith in the visit to Sekisui House in May 2017).


Figure 125. (left) Disassembling visual instruction in the top right of the photo (Photo by Author in the visit to Sekisui House in May 2017). Figure 126. (right) Components of disassembled tatami matt (Photo by Author in the visit to Sekisui House in May 2017).

Sekisui House adds value from the material obtained from the recycling process. For example, the polystyrene extracted from the tatami mats is melted, processed and used for insulation material for new houses. Eggshells, used in the factory canteen, are taken to the recycling facilities, crushed and processes to produce material to paint lines in baseball fields. Adding value is an integral part of lean manufacturing. The lean techniques used in the recycling process are equally used in all the production process of Sekisui House.

Sekisui Heim

Manufacturing capacity

Sekisui Heim possesses eight manufacturing plants, two research and design centres (laboratories) and multiple sales offices. The following image presents the facilities of Sekisui Heim in Japan (Fig. 127).

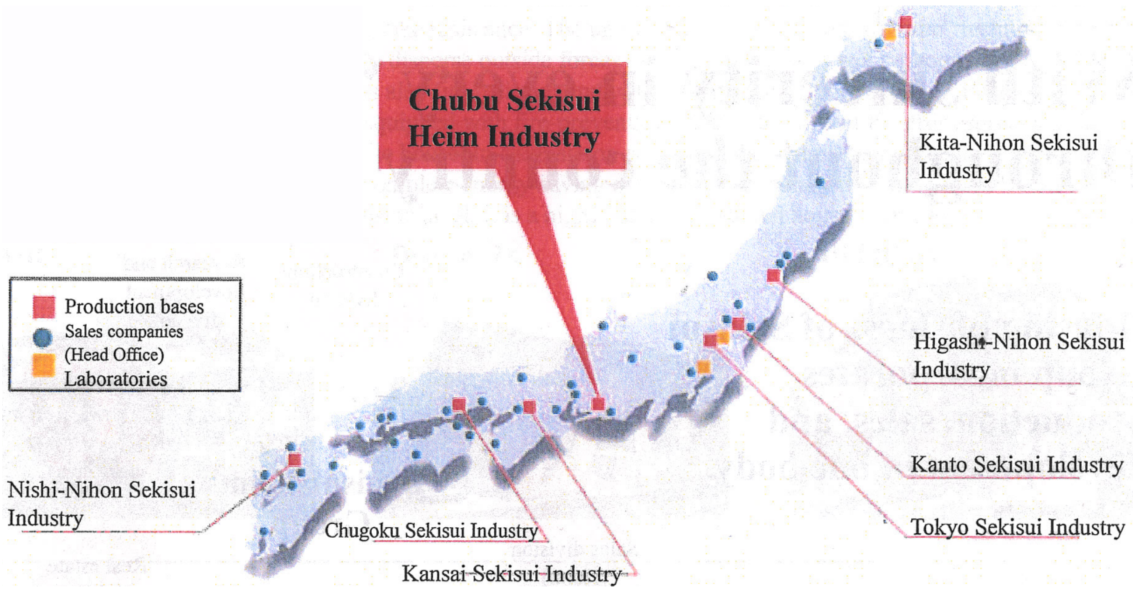


Figure 127. Sekisui Heim's facilities (From material collected in the visit to the Sekisui's Heim 'Chubu' facilities (highlighted) of Sekisui Heim in May 2017).

A Sekisui Heim factory can produce 135 different units per day (Furuse & Katano, 2006:352). Their production is based on sophisticated machinery and robotics, which allows them to have flexible production within a production-line manufacturing organisation (Bock & Linner, 2015:137-141).

As an example, Sekisui Heim's Tokyo plant has the capacity to produce 8,000 modular units per month, which accounts for 600 houses. It employs around 1,000 people and can produce modular units made of steel or timber material (Gann, 1996:446).

The Sekisui Heim factories are organised to follow a standardised production process based on a central production line supported with parallel production processes and workstations. The following image shows the machinery arrangement and scale of the standard Sekisui Heim assembly factory. The highlighted areas belong to the main production line (Fig. 128).

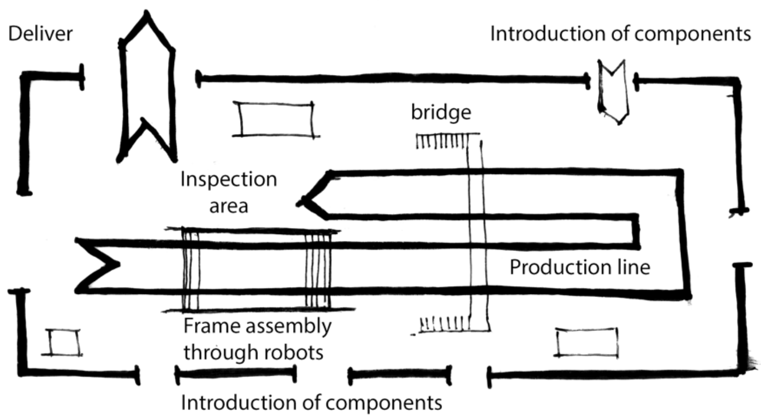


Figure 128. Diagram of Sekisui's Heim steel frame production facilities (by Author from primary material provided by Sekisui Heim in May 2016).

Most of Sekisui's Heim houses are produced using steel frames. However, Sekisui Heim can produce modular units from steel or wood. Factories, as Kita Nihon in Hokkaido, possess flexible manufacturing lines, where the initial manufacturing process is divided depending on the structural material, but the assembling line is shared (Fig. 129)

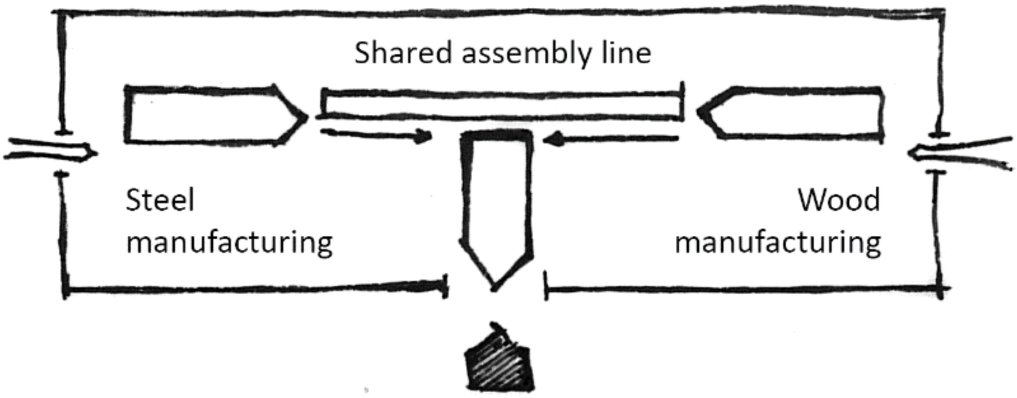


Figure 129. Diagram of the shared assembly line for steel and wood frame units of Sekisui Heim (by Author from primary material provided by Sekisui Heim in May 2016).

Production process

The production process of a Sekisui Heim steel frame house is described as follows. First, (1) assembly parts and elements are produced adjacently to the main production line. Then, (2) steel frames are used to assemble the module structure. (3) Outside wall panels are installed to the three-dimensional frames. (4) The insulation material is attached to the panels and (5) covered with inside wall panels. Then, (6) partitions and equipment are installed. (7) Finishing works on the interior. Finally, (8) the module is inspected, packaged and (9) ship for delivery (Sekisui Heim Group). Each house typically consists of 12 to 15 units. Production begins three days before units are shipped to the site. The following diagram exemplifies the Sekisui Heim production line (Fig. 130).

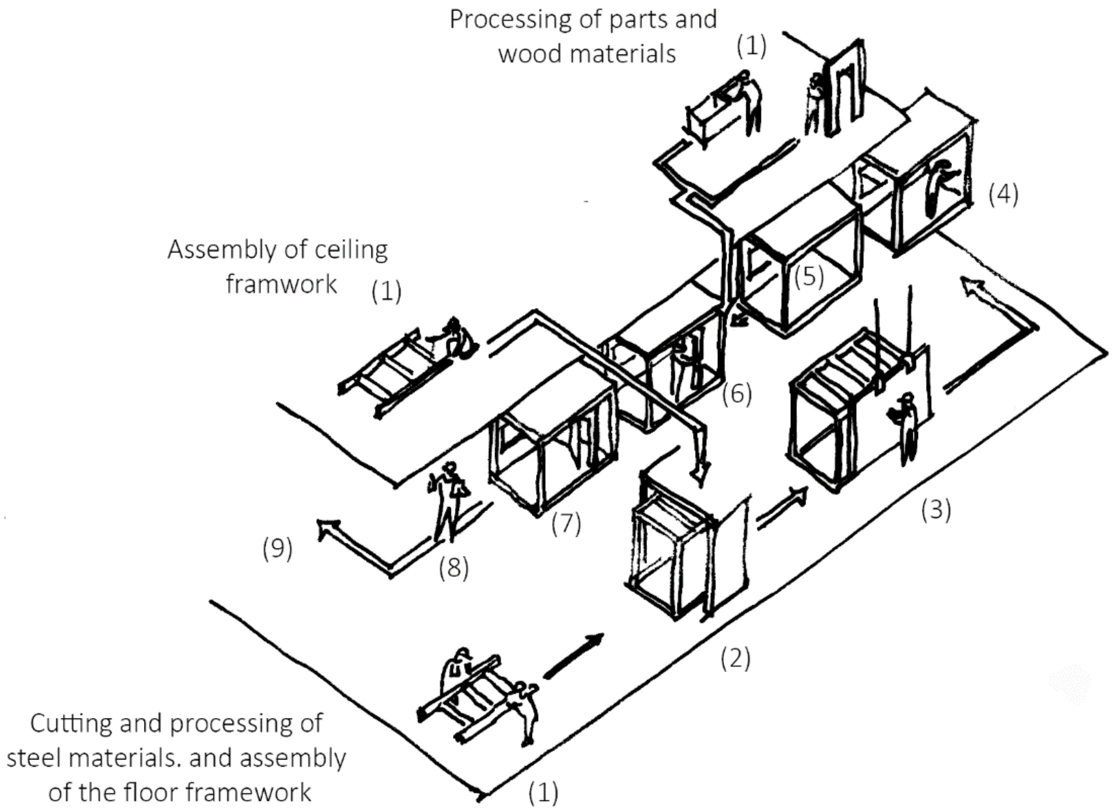


Figure 130. Sekisui Heim assembly line system (by Author from primary material provided by Sekisui Heim during the factory visit in May 2016).

Each of the Sekisui Heim's houses is made up of around 10,000 different component types. However, Sekisui Heim holds stocks of over 270,000 components, which are needed to satisfy any of the possible variations to the standardised models. The following images show the interior of a Sekisui Heim factory, its main production line and the development of the modules (Fig. 131 & 132)
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Figure 131. (left) Sekisui Heim assembly line (From primary material provided by Sekisui Heim in May 2016). Figure 132. (right) Change of direction in Sekisui Heim Chubu factory assembly line (Photo by the Author in fieldwork at Sekisui Heim in May 2016)

Sekisui Heim uses multiple assembly lines that work in parallel, where the different components are pre-assembled before being introduced to the main assembly line, to ensure efficient and continuous production. The production start times can be delayed on the main assembly line such that all the components necessary for the completion of a house. It takes approximately three hours to complete one unit. The following diagram exemplifies the combination of sublines in a standard layout of a Sekisui Heim assembly line (Fig. 133).

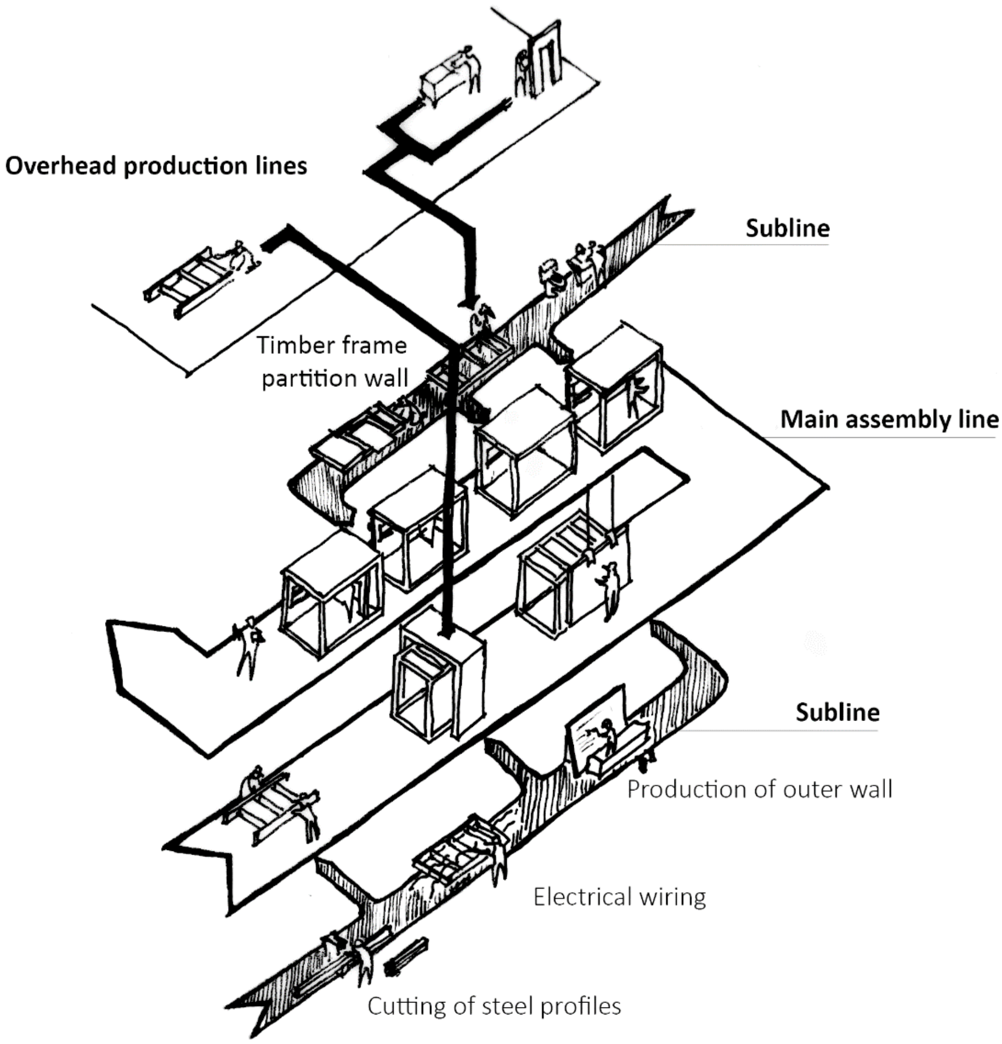


Figure 133. Sekisui Heim assembly line system including sublines (by the Author from primary material provided by Sekisui Heim during the factory visit in May 2016, and information from Bock & Linner, 2015:142,187-189).

Sekisui Heim's full production line operates in over twenty stages and works through orders of house by house. Production of components and manufacturing of raw material works independently from the assembly line. Material, components, pre-assembled kitchen and bathroom pods, wall panels, and windows and doors are supplied to the assembly line in different stages. (Figs. 134 & 135)

Figure 134. (left) Sekisui Heim's internal crane system to move wall panels. Figure 135. (right) Fixing of stairs in Sekisui Heim factory (From primary material provided by Sekisui Heim in May 2016)

Workers install these components according to detailed work schedules. Production is organised in quality loops and thresholds similar to those found in the automobile industry. The following diagram exemplifies how material and components are supplied to the assembly production flow (Fig. 136).

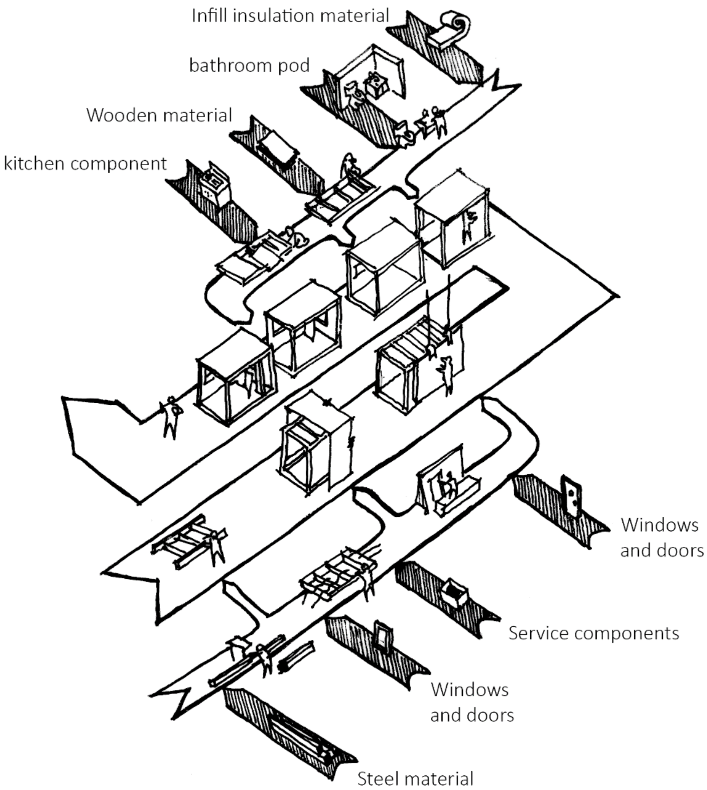


Figure 136. Sekisui Heim assembly line material and components supply (by the Author from primary material provided by Sekisui Heim during the factory visit in May 2016).

The assembly line varies in each order. There are about seventy kinds of three-dimensional units. Most of them are cuboids, but there are trapezoidal units used for pitched roofs. The production line has multiple checkpoints where the modules are inspected to detect any defect and ensure quality. If any defect is detected, the production line is stopped until the problem is fixed, which follows lean principles. The following image shows the inspection of the modules once the furniture has been fixed to the structure (Fig. 137).

Figure 137. Inspection checkpoint at a Sekisui Heim factory (From primary material provided by Sekisui Heim in May 2016).

The UK scenario

Robertson Timber Engineering

Manufacturing capacity

Robertson possesses two factories in the UK; one in Elgin, Scotland and another in Seaham, England. Both facilities produce timber frame panels. Elgin timber engineering facilities opened in 1986 and the Seaham facilities in 2003. The following images show the Robertson Timber Engineering facilities (Figs. 138& 139).

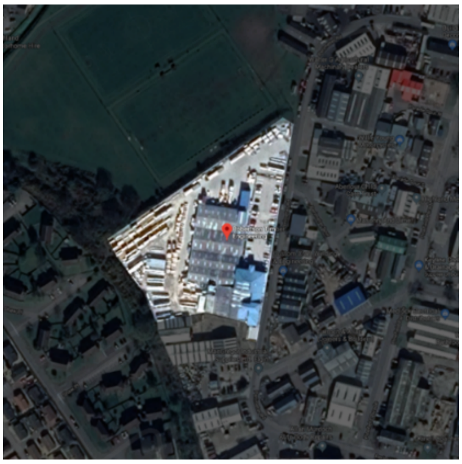



Figure 138. (left) Robertson manufacturing facilities in Elgin, Scotland. Figure 139. (right) Robertson manufacturing facilities in Seaham, England (images in the same scale by Author with information from Google Earth).

The Seaham facilities have an area of 3,700 m^2. Its cost was of 2.3 million pounds including machinery. It has office space, storage (exterior and interior) and manufacturing area. The factory is divided into the timber frame production and timber cassette assembly areas. The timber frame production is arranged as a chain-line organisation without buffer zones. The timber cassette assembly area is arranged as a workshop-like organisation. The following plan shows the organisational plan of the factory (Fig. 140).

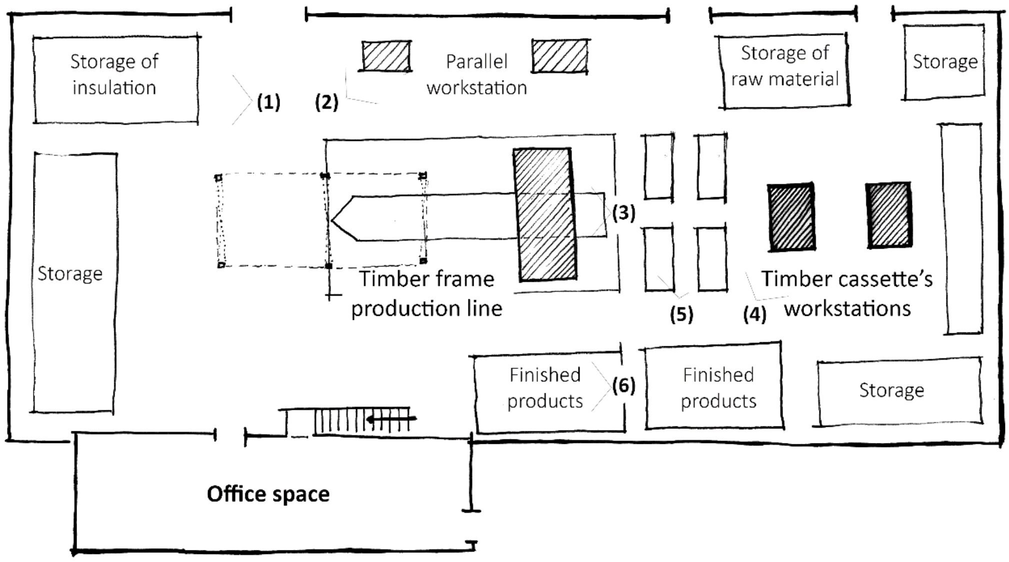


Figure 140. Plan of Robertson's Seaham timber facility (by the Author based on the visit in June 2017).

The Robertson factory layout is described as follows. It has an office area located in the southeast corner. In the north part of the factory there is a manoeuvring yard that also works as a storage of incoming material and for organising the construction kits ready for delivery. In the main warehouse, there are diverse storage areas for raw material and prefabricated components manufactured by other companies as (1) insulation material, windows, membranes and structural timber beams. Adjacent to the main production areas, there are (2) parallel workstation that prepares the material used to complete the wall frames or floor cassettes. The frame production line starts with a (3) CNC framework machinery. The (4) timber cassette workstations are located in between (5) storage area to have direct access to the material. The outcome produced in the cassette stations is (6) storage indoors where it is tagged, while the timber frame panels are carried to the manoeuvring yard. The following images illustrate the factory layout and are indicated in the plan (Figs. 140, 142, 143, 144, 145 & 146).

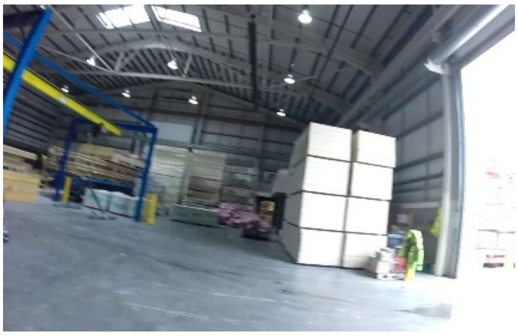
 

Figure 141. (left) Storage of insulation material. (Photo by the Author based on the visit to Robertson's Seaham facilities in June 2017) Figure 142. (right) (2) Parallel workstations. (photo by the Author based on the visit to Robertson's Seaham facilities in June 2017)

Figure 143. (left) (3) Timber frame production line (image taken from Robertson Timber Engineering website). Figure 144. (right) (4) Timber cassette workshop station. (photo by the Author based on the visit to Robertson's Seaham facilities in June 2017)

Figure 145. (left) (5) Storage of components for assembly of cassettes. (Photo by the Author based on the visit to Robertson's Seaham facilities in June 2017) Figure 146. (right) (3) Storage of finished and tagged floor cassettes. (photo by the Author based on the visit to Robertson's Seaham facilities in June 2017).

Production process

Robertson Timber Engineering produces timber frame wall panels and floor cassettes.

Robertson Construction, independent from Robertson Timber Engineering, manage the construction on-site including the incorporation of other construction components. Robertson prefers to build using their products; however, they adequate to the developer's desires. Ben Murphy (2018)– Framework Operations Coordinator at Robertson Construction group– explains the preference on a construction system as a standard from a contractor perspective.

> *'Robertson only manufactures timber wall panels which are used on all residential project as a company standard. In other words, we don't use outside timber wall panel manufacturers, but for roof trusses, we subcontract that out. We only use a different frame when the client [not final user][21] requires that we build in a different method.'*

Robertson's timber frame production is organised as follows. First, (1) timber joists are delivered to the factory and stock. Then, (2) the timber joists are cut to specifications in workstations outside the timber frame manufacturing line. (3) The frame structure is assembled using a CNC framework station machine. (4) The frames are covered with plywood. Robertson can produce open or closed timber frame panels. Then, (5) windows, doors, water-proof membrane and insulation material are fitted into the frame to specifications. (6) The material is organised and packaged. Finishing materials are placed on-site. Finally, (7) the wall panels are delivered to site. The following diagram exemplifies the timber production line of Robertson's facility in Seaham in the UK (Fig. 147).

[21] Contractors refer to clients to the companies or organisations in charge of the housing development; these could be housing developers, housing associations, local authorities or private investors.

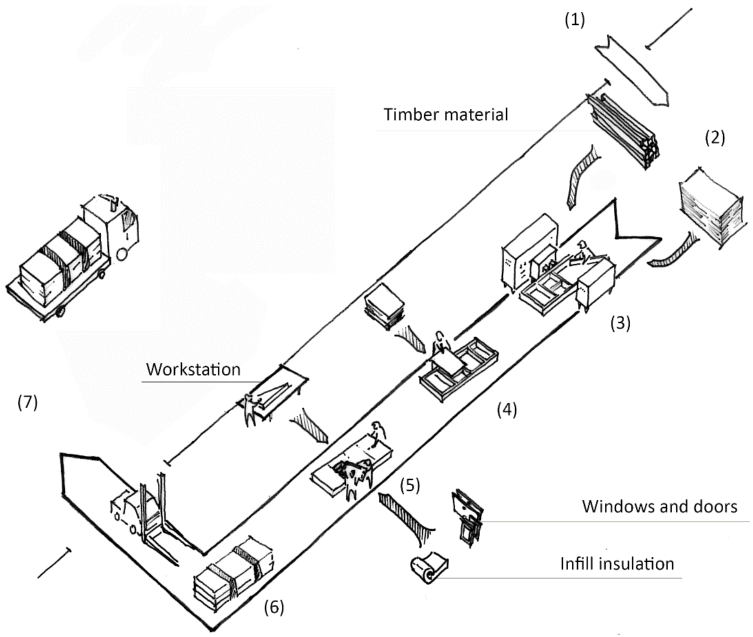


Figure 147. production line based on Seaham facility (by the Author produced through information collected from the visit to Robertson's Seaham facilities in June 2017

Robertson produces timber cassettes using a workshop-like arrangement and low-tech equipment, like saws and nail guns. Material is transported using a crane that covers most of the warehouse. Robertson uses timber I-beam parts produced by other manufacturers because they do not possess the machinery to produce them. They add value to the I-beams by transforming them into floor cassettes. The following image shows an arranged package of I-beams next to the workstation (Fig. 148).

Figure 148. I-beams used by Robertson for the production of floor cassette (photo by the Author from the visit to Robertson Seaham facilities in June 2017).

The construction kit is then taken to site for its assembly. Robertson Construction Group deals with the construction on-site, including foundations, assembly of prefabricated components and first, second and third fixes.

The assembling of Robertson's components is described as follows. First, (1) the wall panels (with windows) are craned, distributed and fixed over the foundations. Then, (2) partition walls and internal, non-load bearing material is placed. (3) Floor cassettes are arranged, lifted and fixed to create the internal floors. Then, (4) another load of wall panels are placed. Finally, (5) the roof is placed over the wall perimeter and covered with a waterproof membrane. The following series of images exemplify the assembling process (Fig. 149)

Figure 149. Robertson assembling process for housing development (Snapshots of Robertson Group, 2015).

Scotframe

Manufacturing capacity

Scotframe possesses two factories, both in Scotland. One factory located in Cumbernauld, between Edinburgh and Glasgow; and the other one in Aberdeenshire in the northeast of the country. Scotframe factories produce timber frame panels for walls, floors and roofs. The Aberdeenshire facilities have equipment for insulation injection. The following images show the aerial view of both Scotframe facilities (Figs. 150 & 151).

Figure 150. (left) Scotframe manufacturing facilities in Cumbernauld, Scotland. Figure 151. (right) Scotframe manufacturing facilities in Aberdeenshire, Scotland (images in the same scale by Author with information from Google Earth).

The Scotframe Cumbernauld facilities have an area of 7,000 m^2. The production area contains operation of four simultaneous manufacturing processes; wall and floor timber frame, roof timber frame, door fitting and the main workstation to finish and inject insulation to all timber frame panels. This factory uses production-line, chain-like and workshop-like organisation arrangements. The following image illustrates the plan of Scotframe's Cumbernauld plant (Fig. 152).

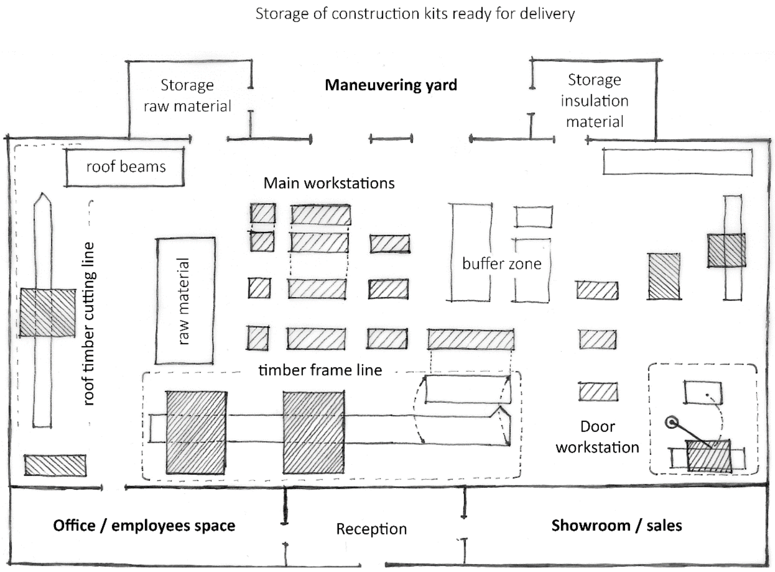


Figure 152. Plan of Scotframe's factory in Cumbernauld, Scotland (by the Author based on the visit in March 2017).

Production process

The timber frames used for walls and floors are manufactured using a hybrid manufacturing arrangement that starts with a production-line organisation and finishes with a workshop-like organisation. First, (1) timber beams are taken from storage, (2) cut and fixed to the lengths specified for each frame. Then, (3) the timber beams are fed into the CNC framework station machine, similar to the one in Robertson's factory. The timber frame is assembled by the machine-assisted by staff. Once the frame is completed is pushed automatically through a conveyor line towards a multifunction bridge machinery. This, (4) nails the OSB boards to the timber frame and cut out openings. (5) The timber frame reaches the end of the conveyor line, and it is flipped using a 'butterfly' turning table. Then is put back into the conveyor line and placed back under the multifunction bridge to cover the other side of the frame. Then, it is craned to the main workstation area, where (6) insulation is injected into it. Finally, (7) the panels are carried and grouped in the manoeuvring yard for delivery. The following images illustrate the wall and floor framing process in relation to the factory's plan and photographs (Figs. 153, 154, 155, 156, 157, 158, 159, 160, 161 & 162).

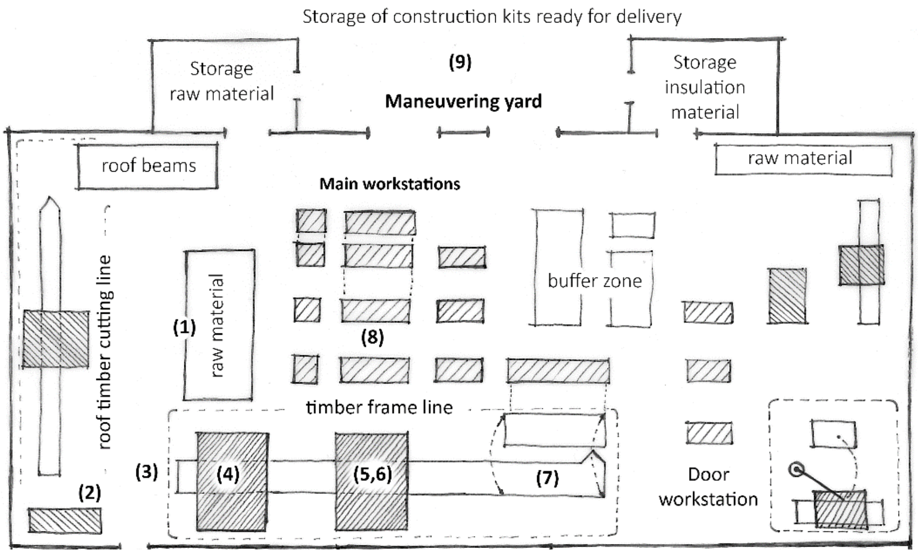


Figure 153. Manufacturing process of timber frame panels for walls and floors (by the Author based on the visit in March 2017).

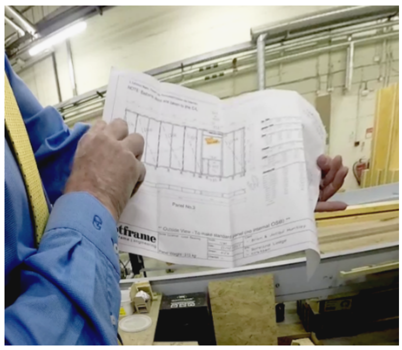


Figure 154. (left) (1) Storage of beams. Figure 155. (middle) (2) Support workstation for cutting and fixing beams used for framing. Figure 156. (right) (3) Timber frame technical drawing.



Figure 157. (left) (4) Automated CNC framework station machine. Figure 158. (middle) (5) Multifunction bridge machinery, front. Figure 159. (right) (6) Multifunction bridge machinery.

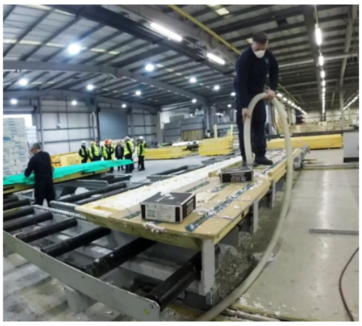



Figure 160. (left). (7) Butterfly turntable and crane to move panels. Figure 161. (middle). (8) Insulation injection at the main workstation Figure 162. (right) (9) Floor and wall panels ready for delivery (all photos by the Author of fieldwork visit to Scotframe in March 2017).

Roof timber frame manufacturing is arranged as a workshop-like organisation supported with a CNC machinery. First, (1) timber beams are taken from the storage area and positioned in the conveyor line. Then, (2) timber beams are cut using a multiaxial and multi-tool carpentry automated machine. This machine measures, cut in angles, raster, drills and tags the beams. (3) The information is sent from the engineering offices, and factory staff need to activate the tasks. (4) The ready-cut beams are stored in a buffer area. (5) Rood frames are assembled by hand in the main workstation. The open frames are covered with OSB (Oriented strand board) boards if closed panels are required. Closed panels are covered with a membrane and insulation is injected, such as in the wall frame process. Finally, (6) the roof panels are stored outside for delivery. The following images illustrate the roof framing process in relation to the factory's plan and photographs (Figs. 163, 164, 165, 166, 167, 168 & 169).

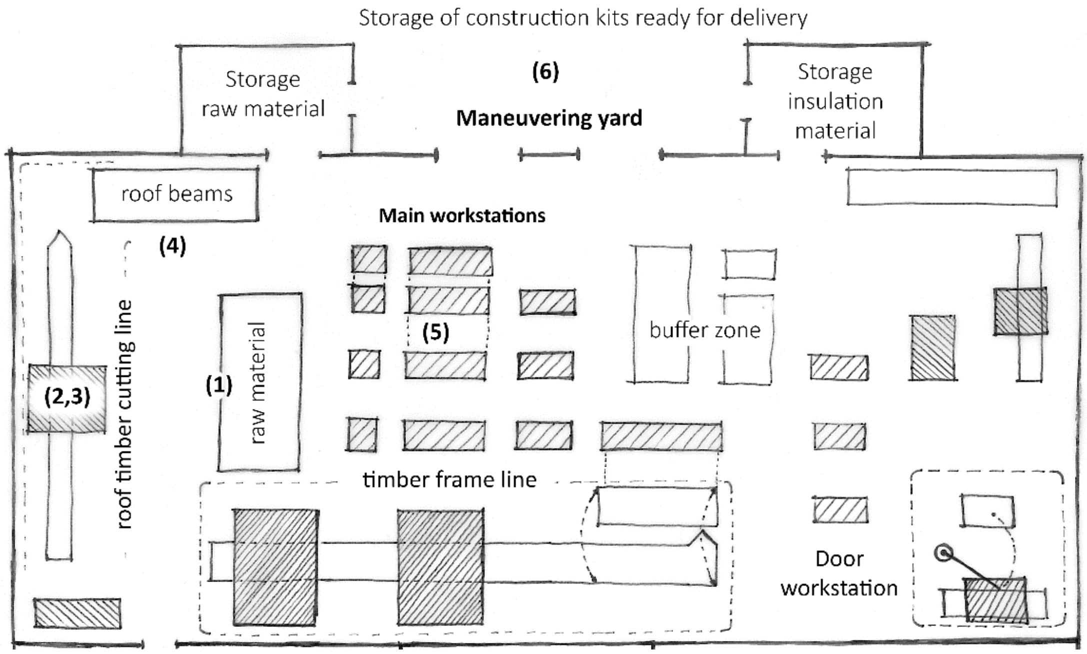


Figure 163. Manufacturing process of roof panels (by the Author based on the visit in March 2017).

Figure 164. (left) (1) Storage of beams. Figure 165. (right) (2) Multiaxial carpentry machinery.

Figure 166. (3) Cutting information in machine sent from the engineering office. Figure 167. (4) Temporary storage for cut beams.

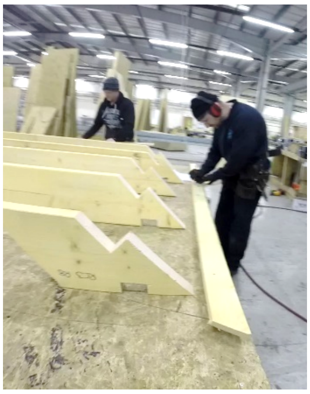
 

Figure 168. (5) Assembly of roof frame in workstations. Figure 169. (6) Construction kit fixed to a lorry (Photos by the Author of fieldwork visit to Scotframe in March 2017).

Scotframe facilities also possess machinery to fix standardised door panels for easy assembly to the frame panels. The doors panels are outsourced and are already painted and coated. This process is arranged as in a workshop-like organisation supported by automated machinery for boring holes for locksets and hinges, and a saw to cut the door frame. First, (1) door type is selected from inventory corresponding to the design. Then, (2) standardised door panels are fed with a crane to the automated machinery, which will boreholes for lockets and hinges. In parallel, (3) door frames are cut using stationary saws. Then, (4) doors are fitted into door frames in the door workstations. Finally, (5) the door kits are stored internally for later assembly into wall frames. The following images illustrate the door fitting process in relation to the factory's plan and photographs (Figs. 170, 171, 172, 173, 174 & 175).

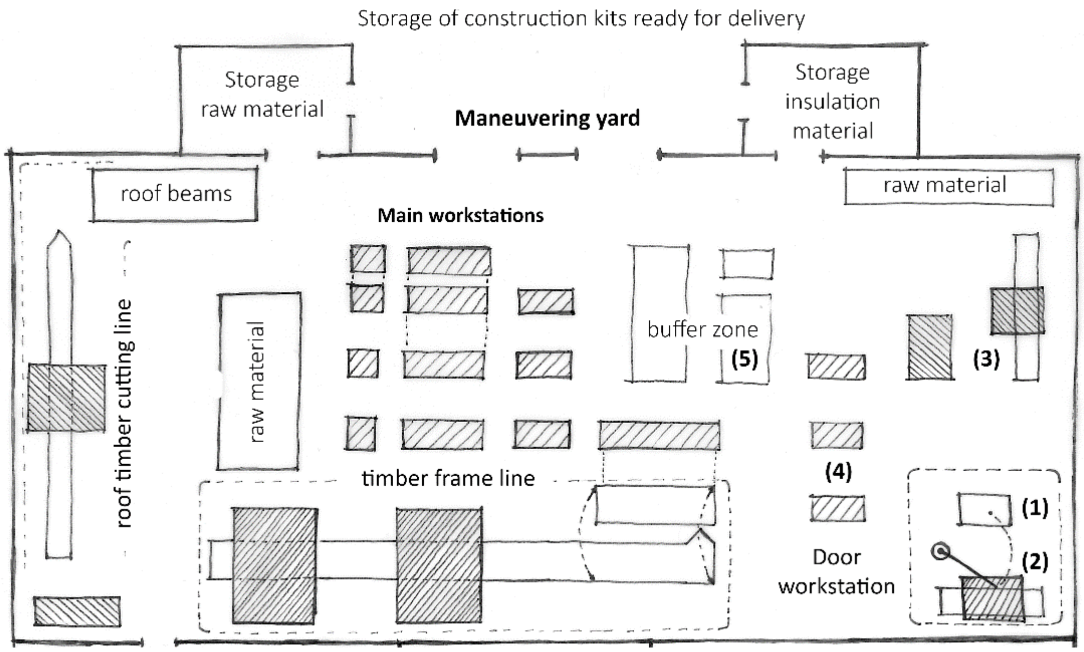


Figure 170. Manufacturing process of door panels and frames (by the Author based on the visit in March 2017).

Figure 171. (left) (1) Standardised outsourced door panels. Figure 172. (right) (2) Feeding of door panels into automated machinery.

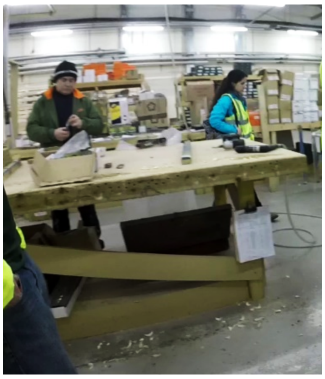


Figure 173. (left) (3) Stationary saw for cutting door frames, also used for cutting OSB panels for roof frames. Figure 174. (middle) (4) Door workstations, with low-tech tools. Figure 175. (right) (5) Doors fitted into frames and storage for later assembly or delivery (photos by the Author of fieldwork visit to Scotframe in March 2017).

Scotframe's factory in Aberdeenshire has the machinery to inject expandable insulation machinery using a press to control the injection pressure and shape of the frame. This insulation process provides lower thermal bridges and, consequently, wall components with lower U-values. It is made from 86% recyclable vegetable oil. Scotframe's panels have a U-values range that varies from 0.09 to 0.23; which complies with the Passive House guidelines that suggest U-values between 0.10 to 0.15. The following image shows the injection of expandable insulation into timber frames (Fig. 176).

Figure 176. Insulation injection process (From Scotframe technical brochure collected in fieldwork).

Scotframe applies lean manufacturing principles; not as sophisticated as Sekisui House and Sekisui Heim, but to a level that allows them to produce customisable products with control manufacturing costs.

Carbon dynamic

Manufacturing capacity

Carbon Dynamic possess only one manufacturing facility, located in Invergordon, Scotland. Carbon Dynamic operations are centralised to this facility, including manufacturing, design, management and sales. The following images show the dimensions of Carbon Dynamic (Figs. 177 & 178).

Figure 177. (left) Carbon Dynamic in Industrial park in Invergordon, Scotland (image by Author with information from Google Earth). Figure 178. (right) Carbon Dynamic manufacturing facilities (from Carbon Dynamic promotional video).

Carbon Dynamic uses a workbench-like organisation, where the tools and workers move from module to module to complete the production process. Carbon Dynamic does not manufacture construction components. They assemble building modules using outsourced prefabricated components. Therefore, its facilities are essentially an assembly warehouse. It is organised to have multiple workstations were modules are assembled distributed along a central transportation corridor for efficient transportation of material. The modules are exposed and facing each other, allowing monitoring of the construction process and quality control. Also, the movement of modules is avoided, and thus, the requirement of conveyor lines and multiple cranes. The Carbon Dynamic facilities possess only one overhead crane. The following images illustrate the layout and arrangement of Carbon Dynamic facilities (Figs. 180, 180 & 181).

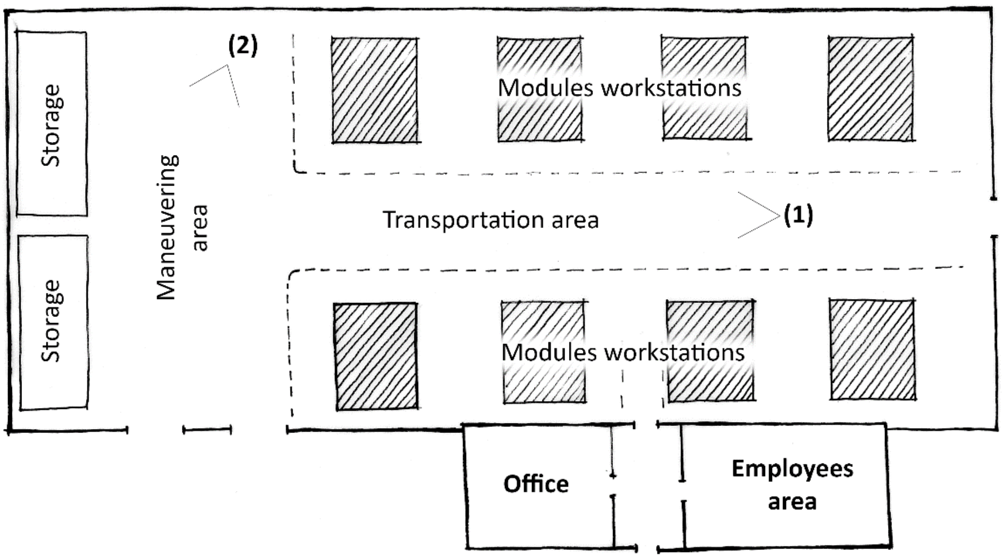
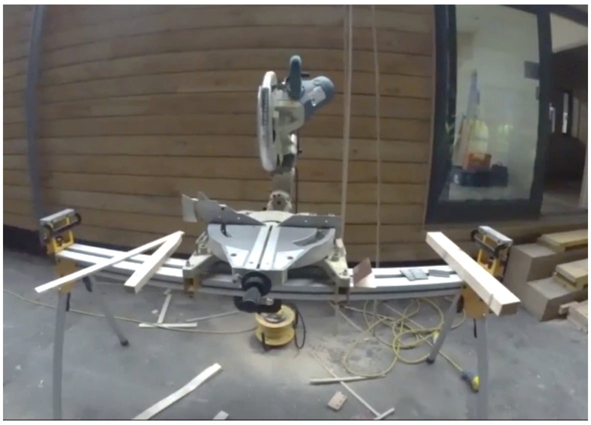


Figure 179. Manufacturing process of roof panels (by the Author based on the visit in March 2016).

Figure 180. (left). Carbon Dynamic warehouse area with modules under construction at both sides of the transportation area (photo by the Author in fieldwork visit in March 2016). Figure 181. (right) Carbon Dynamic internal manoeuvring area (image from Carbon Dynamic promotional video).

Carbon Dynamic’s machinery is not fixed to a place. Their tools are portable, detached or fixed to mobile stations. Thus, the material does not need to move from workstations to the machinery and back again. The following images show the tools used in Carbon Dynamic and their proximity to modules (Figs. 182 & 183).



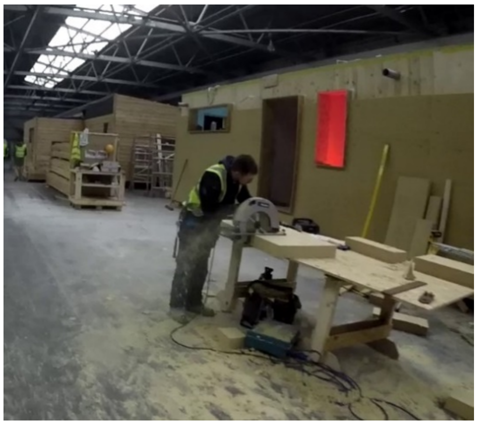


Figure 182. (left) Backsaw and portable station. Figure 183. (right) Saw attached to workshop table (photos by the Author in fieldwork visit in March 2016).

Carbon Dynamic achieves lean principles of efficiency with low-tech tools and machinery, in the sense that movement of material and staff is minimised, and use pull production process with quick changeovers.

Production process

Carbon Dynamic use a workbench-like organisation arrangement for their production. A system associated with craft production, as explained in chapter 3. The outsourced construction components are designed and produced for assembly, which means they are already measured, cut and produced to the specification of each project. Carbon Dynamic orders these components only when the design of the buildings is agreed with the clients; in other words, they use a pull system. The manufacturers produce personalised construction components for Carbon Dynamic, including structural panels, partitions walls, doors and windows. The manufacturers most probably use manufacturing systems and arrangements more associated with mass production and mass customisation.

As an example, Carbon Dynamic works with Cross Laminate Timber (CLT) structural panels. Carbon dynamic does not possess a CLT press or vacuum; they outsource this material from manufacturers. The CLT manufacturers provide Carbon Dynamic with personalised panels, in terms of thickness, dimensions, shapes and cut-out of openings. Accordingly, Carbon Dynamic avoid investment in machinery, storage area and waste of material (from cuttings). The doors and windows are acquired in the same way.

The Carbon dynamic process, including ordering construction components, is described as follows. First, (1) the architectural design is defined and agreed by the client. Then, (2) the CLT structural panels are ordered from manufacturers, which personalise the panels in size, dimensions and cutting-out openings. The panels are delivered to Carbon Dynamic facilities. (3) The CLT panels are assembled into modules. In parallel, (4) additional personalised components, such as doors and windows, are ordered from other manufacturers; which are then attached to the modules. The modules are covered with insulation and finishing materials. Kitchen, toilet, bath and furniture are installed. Electrical cables and water pipes are installed. Finish coatings and plaster are also fixed on factory. Carbon Dynamic works over 80% of construction off-site. (5) Once the modules are finished, they are transported to site;

and finally, (6) craned into the site and fixed together. The following image illustrates the Carbon Dynamic's production process (Fig. 184).

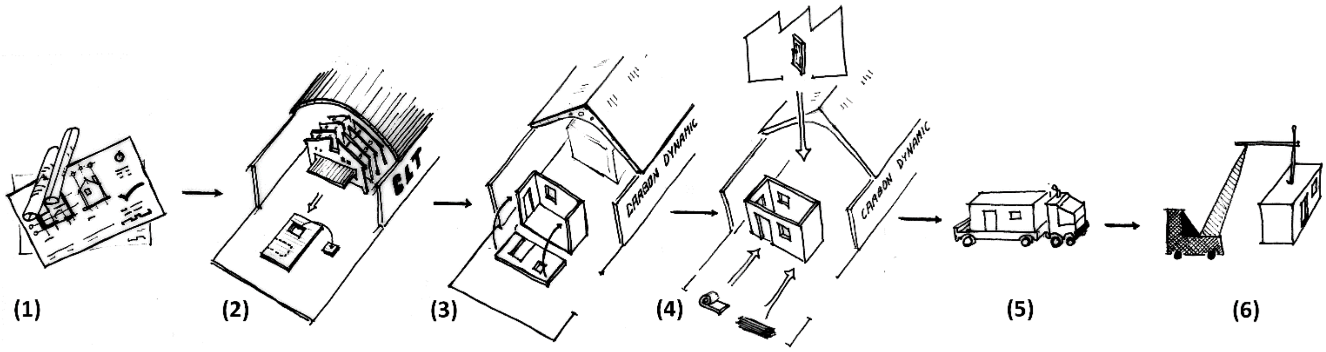


Figure 184. Carbon Dynamic production process (by the Author based on the visit to Carbon Dynamic facilities in March 2016).

The off-site assembly process emulates the construction process seen on on-site constructions that use CLT panel systems. Carbon Dynamic opts for an off-site solution because construction management is facilitated. The following images show the different stages of the assembly process in Carbon Dynamic factory. The first image shows a module where the CLT panels have been already assembled. Window frame bases, made of plywood boards, are placed and contour the insulation. Insulation boards are cut and placed to cover the modules. Tools and material close to module workstation, insulation material in the left side of the image and saws and other equipment in the right (Fig. 185)

Figure 185. Assembly of Carbon Dynamic module, early-stage (photo by the Author from in fieldwork visit in March 2016).

The following image shows a module covered with a waterproof membrane and timber battens to receive the cladding. During this stage, internal furniture and equipment are installed (Fig. 186).

Figure 186. Assembly of Carbon Dynamic module, middle stage (photo by the Author from in fieldwork visit in March 2016).

The following image shows the final stage of the module. By this stage, windows are already fixed. The image shows the cladding process, where the cladding material is set close to the module for quick assembly. The roof is produced separately and fixed on-site. (Fig. 187)

Figure 187. of Carbon Dynamic module, final stage (photo by the Author from in fieldwork visit in March 2016).

Comparison

This chapter analysed five house manufacturing companies; two in Japan and three in the UK. The Japanese companies– Sekisui House and Sekisui Heim– have significantly higher revenue and production volume than the ones in the UK– Robertson, Scotframe and Carbon Dynamic. As explained in chapter 4 & 5, the financial, volume difference and machinery capacity are aspects that relate to the countries' contextual conditions. Taking-out these aspects, the selected companies share plenty of characteristics, including the selection of delay in the supply chain, manufacturing organisation and construction systems. The following table shows the differences and similarities of the selected companies (Table 19).

Table 19. Comparison of House manufacturing companies in Japan and the UK, selected for this research.

	Company	**Revenue (M)**	**Houses per year / No. of factories**	**Delay supply chain strategy**	**Manufacturing organisation**	**Structural material**	**Construction system**	**Off-site / On-site**
Japan	**Sekisui House**	£ 14,060	13,600 / 5	Make to order	Flow line-like, group-like, production-line	Steel or wood	Panelised	60/40 %
	Sekisui Heim	£ 7,388	10,500 / 8	Assemble to order	Flow line-like, production-line	Steel or wood	Modular	80/20 %
UK	**Robertson**	£ 565*	1,000 / 2	Assemble to order**	Flow line-like, workshop-like	Wood	Panelised	variable
	Scotframe	£ 30	1,500 / 2	Assemble to order	Flow line-like, workshop-like, production-line	Wood	Panelised	>50/- %
	Carbon Dynamic	£ 3	<100 / 1	Assemble to order	workbench-like	Wood	Modular	85/15%

***Whole Robertson Group. **Considering Robertson Timber Engineering independent from Robertson Group.**

The five companies selected work with wood structure; only the Japanese companies use steel for the structure of their houses. Three of the companies selected use panelised construction systems. Sekisui Heim & Carbon Dynamic, which use a modular construction system, production management focus in production control. Sekisui House, Sekisui Heim & Scotframe use production-line organisation arrangements. These companies manufacture sophisticated construction components; Sekisui House produces concrete and ceramic panels, Sekisui Heim three dimensional modules and Scotframe insulated timber frame panels. Robertson's timber frame panels do not have injected insulation, which is a manufacturing dependant process.

Carbon Dynamic uses a workbench-like organisation system because they focus on assembling and do not produce any construction component.

The delay supply chain strategy determines the company's level of customisation or standardisation, as explained in chapter 3. Four of the five companies use assemble to order delay supply chain strategy. Sekisui House uses make to order approach. Their structural and wall materials are produced to the client's specifications; wood or steel for the structure and concrete or ceramic for walls. Each material follows a different production process. Sekisui's Heim structural material can also vary from steel to wood; however, the production line remains the same; that is why Sekisui Heim is categorised as assembly to order. Robertson Timber Engineering, independent from Robertson Homes, works as an assembly to order company as its production is delayed to fabrication point. However, from a final customer perspective, Robertson Homes is a make to forecast company as it builds houses through speculative processes; this point is explained deeper in chapter 7.

The following diagram illustrates the companies' supply chain in relation to their delay strategy and manufacturing or outsourcing of construction parts and components (Fig. 188).

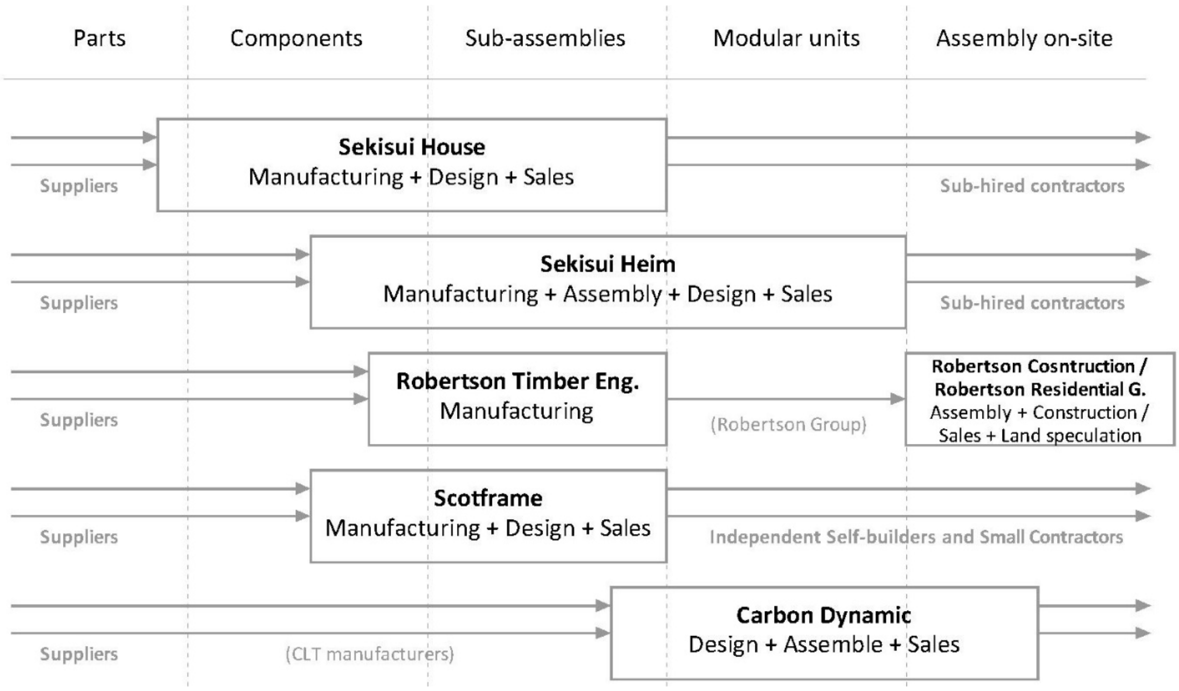


Figure 188. Sekisui House, Sekisui Heim, Robertson, Scotframe and Carbon Dynamic supply chains in relation to delay strategy and outsourcing of components and parts (by the Author, adjusted from Barlow et al., 2003:139—Figure 3; and Gann, 1996:446).

The five companies get parts and components supplied by multiple manufacturers. Sekisui House and Sekisui Heim sub-hire local and independent contractors for the assembly on-site of their dwellings but cover the management and sales processes. From a Sekisui House dwelling, only 25% of the value accounts for manufacturing and assembling in their factories. About 30 % is produced by suppliers of services, which are usually sent directly to the site and installed by subcontractors. Site work accounts for around 20%. Sales, marketing and management overheads account for 25% (Gann, 1996:446). Robertson Group distributes the supply chain into its internal departments. Robertson Timber Engineering only manufactures the construction components, Robertson Construction manages the construction and assembly on-site; while Robertson Homes manage sales and land release. Robertson Timber Engineering is the only manufacturer not involved in the sales and design processes. Scotframe does not build houses, their clients (self-builders) manage the assembly of the construction kit and other construction tasks needed. Carbon Dynamic focus in the assembling of modules off-site and the fitting of modules on-site. Additional construction tasks, as foundations, are managed by the client.

The five companies are using lean and agile strategies. All possess manufacturing systems that allow just-in-time production. In the case of Robertson, a real pull production triggered by final customers is not present because Robertson Timber Engineering is disconnected from the design and selling process.

Japanese manufacturers present more sophisticated lean strategies than UK companies. Multiple mechanised tasks are developed by machines; the quality control checks are strict and programmed; they display clear diagrams and instruction of the manufacturing process for their employees and have reduced their manufacturing waste to zero. However, Robertson, Scotframe and Carbon Dynamic possess very agile manufacturing process without the manufacturing capacity and high levels of lean manufacturing of Sekisui House and Sekisui Heim.

Scotframe is capable of producing six types of wall components, which vary in U-value, using a single production system. Carbon Dynamic produce modular buildings with very low-tech equipment, when compared to Sekisui House, or even Robertson and Scotframe.

A principle of the Toyota Production System, and consequently of lean manufacturing, consists of subdividing the production process, and consider the group of each production step as a contractor or client. Thus, short takt times and production quality are ensured, as explained in chapter 3. Carbon Dynamic does this by involving manufacturers of construction components and parts in their supply chain; consequently, the whole supply chain works as a pull system. Carbon Dynamic use parts and components that depend on industrialised machinery, including CLT panels, double/triple glazing windows, compressed insulation boards, and even, photovoltaic panels. However, Carbon Dynamic did not invest in the machinery needed to produce these components. They only need some cranes to move material around and tools to adjust and fit the material, parts and components to each module.

It is important to highlight that all the companies in observation are capable of producing variable (customisable) outcomes. It directly relates with the fact that all of them present the 'Sub-assemblies' stage in their supply chains. Is in this stage where most components from suppliers are integrated in their modules. Components are also integrated in the 'Assembly-on-site' section. These are the stages where the customisation takes place.

Conclusion

This chapter described the manufacturing capacity and production processes of Sekisui House and Sekisui Heim of Japan, and Robertson, Scotframe and Carbon Dynamic of the UK.

Sekisui House and Sekisui Heim possess very high manufacturing capacity compared to Robertson, Scotframe and Carbon Dynamic. Sekisui House is capable of producing its main construction components and parts. Sekisui Heim has production lines capable of producing modular units from structural wood or steel. Sekisui House and Sekisui Heim possess industrialised machinery and production processes that allow them to produce variable outcomes. Both companies have manufacturing systems capable of producing variable production.

Robertson and Scotframe focus on the manufacturing of timber frame panels. Carbon Dynamic uses outsourced CLT for the assembly of its products. Timber frame panels and CLT allow multiple arrangements, shapes and thicknesses, which allow high variability.

Sekisui House and Sekisui Heim achieve variability through the application of lean and agile manufacturing systems. Robertson Timber Engineering, Scotframe and Carbon Dynamic use process that matches some of the lean and agile systems present in Sekisui House and Sekisui Heim without the need of possessing their manufacturing capacity.

Carbon Dynamic, the company with lower financial assets and manufacturing technology, utilises a pull supply chain that includes suppliers of parts and components that require an industrialised process. Therefore, it possesses the robust capacity to produce customisable zero energy houses without the need for implementing additional management or manufacturing systems, neither investment in manufacturing machinery nor technology.

Scotframe and Robertson’s manufacturing process and its openness to parts and components allow them to produce variable outcomes. Scotframe’s customisation levels are limited because they do not get involved in the assembly of components in-site, where additional features can be added, including furniture, mechanical systems and renewables. Either, Sekisui House and Sekisui Heim, sub-hire contractors for the construction and assembly work on-site, instead of limiting to the manufacturing of the construction kit. Managing construction on-site increases the dwelling’s potential customisation, as multiple parts and components are only applied on-site; all the selected companies process at least 15% of the construction on-site.

Robertson’s customisation potential is limited because the business strategy is focused on speculative development and do not allow a full pull system rooted in the final client’s design decisions.

The comparison between both contexts confirms that the UK has the robust capacity of producing customisable outcomes, despite possessing production facilities with lower capacity and with lighter machinery.

The high robustness of Japanese companies has been determined by their ambition to control the full scale of the construction supply chain. Actually their most heavy machinery relates to the transformation of raw material into construction components.

For example, Sekisui's House oven for concrete wall panels. Sekisui House also possesses machinery to produce more than one construction system. It can build structures in steel and wood. The extended industrial capacity of the Japanese house manufacturers relates to their production volume. At a point in time, it was sensible for them to invest in this machinery to suppress acquiring construction elements from suppliers, referring to the production peaks of the 1970s and 1980s in the Japanese housing history. Actually, most of the machinery present in Sekisui Heim is older than the one used by Scotframe and Robertson, but still more sophisticated and crane dependent. Japanese companies are minimising the investment in robust machinery.

Scotframe and Robertson variability depends on including externally produced components in their houses, as their production capacity is limited to a single construction system, in this case timber frame. Sekisui House has invested in possessing multiple construction systems to allow more variability. However, another alternative is the Carbon Dynamic approach, where they use construction systems produced by other manufacturers. Therefore if they want to provide higher variability simply acquire components from other manufacturers without investing in any machinery and focus on the assembling of modules.

Possessing the robust capacity of producing customisable outcomes, relates to the capacity of integrating multiple components in the production process, which can be produced internally or externally.

The comparison of these companies demonstrated that Robertson, Scotframe and Carbon Dynamic have the robust capacity needed for mass customisation of zero energy houses without increasing or modifying their manufacturing processes. The development of solution space and choice navigation appropriate for mass customisation are related to marketing, design and sales strategies. Chapter 7 describes the marketing, design and sales strategies of selected mass customisers in Japan and manufacturers in the UK to identify the ones that would help to reach mass customisation.

Chapter 7

Front of House: the power of informed customers

This chapter consists of a description of the marketing, co-design and selling strategies of selected Japanese mass customisers and UK house manufacturers through information, data and material collected in the fieldwork. It aims to analyse how house manufacturers in the UK could develop a solution space and choice navigation tool appropriate for the mass customisation of sustainable and zero energy houses. This chapter describes the Japanese housing mass customisers' marketing, co-design and selling strategies, to explain the relationship between these and energy efficiency.

Introduction

Japanese mass customisers lead the commercialisation of zero energy houses, as explained in chapters 1, 3 and 4 (Noguchi et al., 2016:339; Noguchi, 2013:166-167; Noguchi & Hadjri, 2010:898,901-903; Naim & Barlow, 2003:601; Barlow & Ozaki, 2005:13,17; Barlow & Ozaki, 2001:17,25; Johnson, 2007:27; Zero Carbon Hub, 2009:30-31; Bardakci & Whitelock, 2003:471; Davis, 1987:158; Knaack et al., 2012:54-55; Piroozfar & Piller, 2013:7; Iwashita, 2001:295). The UK house manufacturing industry possesses a robust capacity to produce mass customised and zero energy houses, as explained in chapter 6. However, the offer of sustainable houses from house manufacturers in the UK is extremely limited (Davis, 1987:158, Barlow, 1999:32; Naim & Barlow, 2003:593; Lovell et al., 2010:458).

Robust capacity— understood as modular production, flexible automation and flexible workforce— is a requisite for the implementation of mass customisation; however, it represents only one perspective. The production of zero energy homes through mass customisation also requires the development of appropriate solution spaces and navigation tools, including the ability to educate customers about the benefits and advantages of purchasing a zero energy dwelling (Tseng & Piller, 2010:5-6; Piller,2009:74).

The implementation of navigation tools without market orientation decreases the probability of business success. The effectiveness of mass customisation critically depends on the manufacturer's capability to correctly understand customer needs and infuse them into its solution space (Salvador et al., 2019:28,34). Elicitation refers to the process of collecting, understanding customers' needs and guiding them in the design decision-making process; and requires sophisticated, varied and engaging communication strategies (Zipkin, 2001:82,86).

In essence, the solution space manifests the need for rigidity to attain a flexible response to the environment. Market orientation is required to build an effective solution space is particularly critical to the success and long-term survival of a company. Without enough market orientation, investments in toolkits or modularity may have a negative impact (Salvador et al., 2019:28,31,33).

The driver for implementing mass customisation needs to come from the market, rather than from the production capabilities of the manufacturing company. The interest in implementing mass customisation is the demand fragmentation in the market (Bardakci & Whitelock, 2003:464). In the UK, there is an unattended market for sustainable housing (Douglas, 2015:12-13; Parvin et al., 2011:30). Up to 66% of the population would pay a premium price for sustainable products (Brooker, 2019). Among self-builders, 28% of the interested in including photovoltaic solar panels

(Barlow et al., 2001:19). 14% of consumers of new houses in the UK are not satisfied with the quality of their dwellings (HBF, 2019:3).

In mass customisation, the consumer has a direct relationship with the producer and is part of the design process. Thus, the sale is not the end of the marketing process but the beginning of a relationship in which seller and buyer become interdependent (Bardakci & Whitelock, 2003:464; Boër et al., 2018:247-248).

This chapter describes the marketing, co-design and selling processes of selected companies in Japan and the UK to identify the strategies used by Japanese mass customisers not present in the UK. It focuses on the strategies that have a relationship with energy-efficiency and sustainability. This chapter concludes by indicating how marketing, co-design and selling strategies could be improved to have a positive impact on the production of zero energy dwellings in the UK, using Scotframe as an example.

Selection of companies

The companies selected for this research were Sekisui House, Sekisui Heim and Daiwa House in Japan; and Scotframe and Carbon Dynamic in the UK. Regarding chapter 6, Daiwa was added as a study case because it is recognised for providing the highest level of customisation among the Japanese house manufacturers. In the UK, Robertson Timber Engineering was excluded because it does not have a selling department. Robertson Homes (Robertson Residential) follows the selling process of speculative housebuilders in the UK, as explained in chapter 5. The following image illustrates the speculative selling process of Robertson's Home, which is disconnected from the design and manufacturing processes and house buyers select from room count and location (Fig. 189).

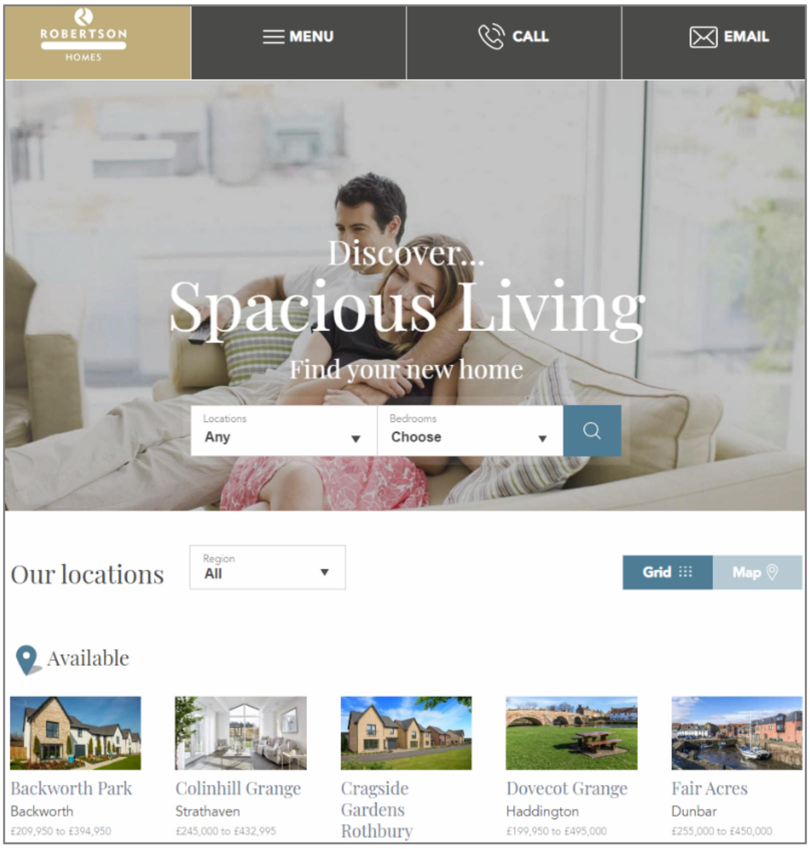


Figure 189. Robertson's Home website homepage (From Robertson Home website).

Sekisui House (Japan)

Sekisui House was selected because of its scale, volume and high sales of zero energy houses. Also, because of its distinctive co-design process based on the interactive involvement of the customers in their sophisticated information centres.

Sekisui House is the largest and one of the most well-known Japanese house manufacturers, as explained in chapter 6. Sekisui House focuses on the upper market segment and is recognised for providing highly customisable houses (Aitchison, 2018:115-116; Noguchi et al., 2016:357-359; Bock & Linner, 2015:149-152; Barlow et al., 2003:137-140).

In 2008, Sekisui House introduced a zero energy model that represented 50% of their detached house sales by 2014 and 76% by 2017. In 2018, Sekisui House received 34,648 orders for net-zero energy houses, the most in Japan. In 2017, their houses produced 84% less CO_2 emissions compared to 1990 (Sekisui House, 2018:4,14,28).

Sekisui Heim: Sekisui Chemical (Japan)

Sekisui Heim was selected because of its focus on energy efficiency and performance. Also, because it provides high levels of customisation despite using modular production, as explained in chapter 6 (Barlow et al., 2003:138-140).

Sekisui Heim focuses on the top end market and specialises in high-precision manufacturing and rigorous quality control; their market niche is very narrow. Accordingly, they are consciously reducing their sales and increasing the cost (and quality) of their houses as a marketing strategy (Bock & Linner, 2015:190; Furuse & Katano, 2006:352).

Sekisui Heim launched its zero energy model in 2004, called ‘Parfait AE’. Sekisui Heim concentrates on providing high-capacity photovoltaic systems. Sekisui Heim collaborates with banks and loaning agencies to provide lower loan rates for houses equipped with solar panels. In 2016, they had a total of 180,000 houses equipped with solar panels, the most in Japan. Sekisui Heim provides the option to follow ‘PassivHaus’ or ‘Plus Energy house’ international standards (Noguchi et al., 2016:354-355; Sekisui Chemical, 2018:33; Bock & Linner, 2015:198).

Daiwa House (Japan)

Daiwa House was selected because it is recognised for providing the most user-friendly selling process and providing the highest level of customisation among the Japanese house manufacturers (Bock & Linner, 2015:159).

Daiwa House started selling houses in 1955. Daiwa has consistently been among the top sellers. Daiwa, different to Sekisui House and Sekisui Heim, extensively subcontracts on-site assembly, local builders and craftsmen. Daiwa serves the mid to top end of the market. Daiwa leads the housing sector in terms of inclusive and age supportive designs and building features (Bock & Linner, 2015:159).

Daiwa offers house models equipped with sophisticated energy monitors and management systems that promote better performance via user behaviour, clamming to reduce carbon emissions by 70% compared to the average Japanese household. The sale of these models accounts for 40% of their sales. Daiwa, as a housing developer, has built an entire neighbourhoods of zero energy dwellings, since 2013 (Kyodo, 2013; Daiwa, 2018:39).

Customised houses account for 10.1% of their business. Daiwa is the house manufacturer with the highest growth rate from 2005 to 2017 (Daiwa, 2018:18). The following image shows Daiwa's business distribution (Fig. 190).

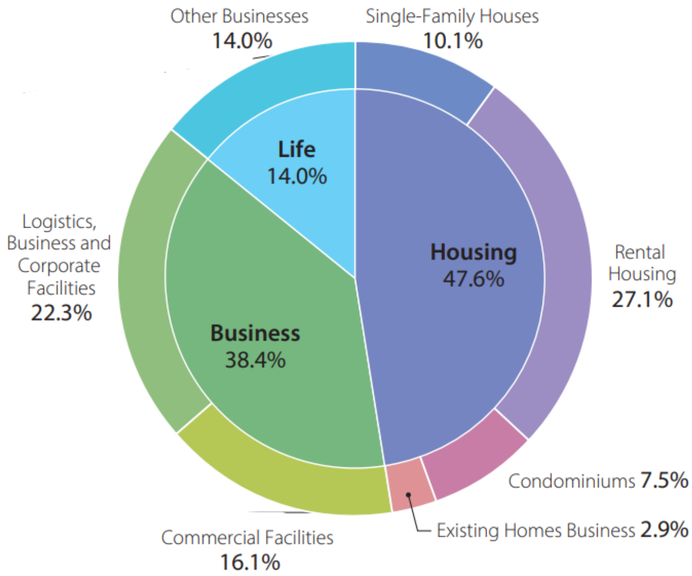


Figure 190. Daiwa House business distribution in 2017 (From Daiwa, 2018:18).

Scotframe (UK)

Scotframe was selected because it is a timber manufacturer, which business is not only centralised on supplying housing developers. Scotframe main business is supplying self-builders with customisable packaged house kits selected from catalogues but also work with bespoke projects, as explained in chapter 6. The following image taken from Scotrframe's website illustrates the bidirectional orientation of their business (Fig. 191).

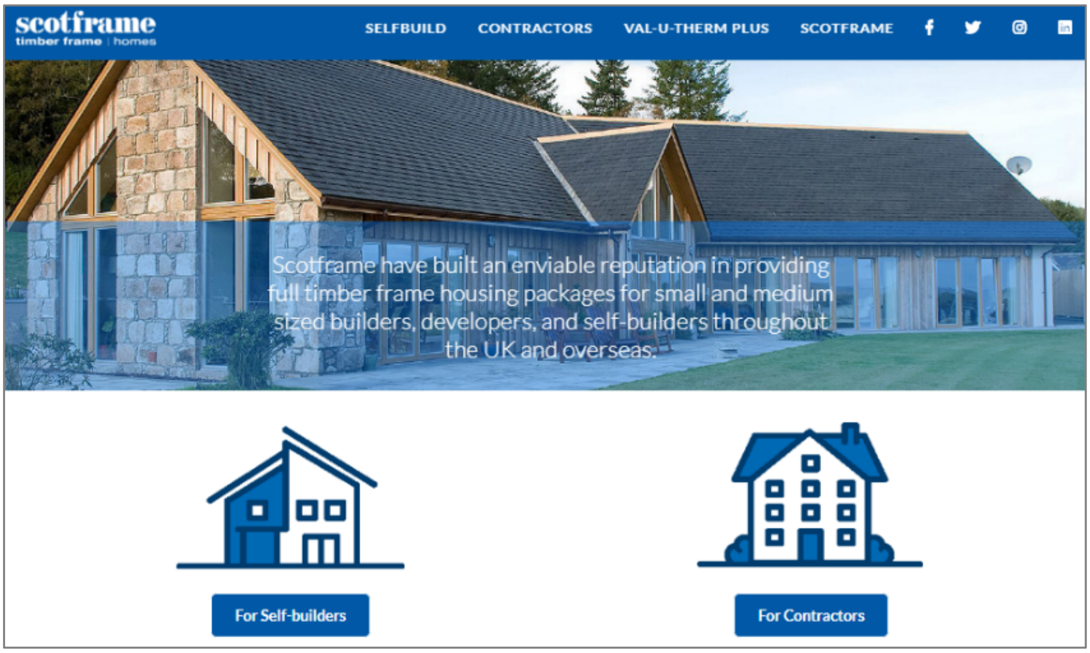


Figure 191. Scotframe's website homepage (From Scotframe website).

Scotframe has developed a production process that allows variable thermal levels on their panels and interchangeability between double and triple glazing windows. Scotframe has a defined solution space and uses catalogues and showrooms as marketing and selling processes. Currently, Scotframe does not include renewables as customisable or add-on features in its construction kits.

Carbon Dynamic

Carbon Dynamic was selected because it is a housing manufacturer that produce personalised dwellings with high levels of thermal performance with low industrial and technological equipment, as explained in chapter 6. Thus, Carbon Dynamic works as an example of how mass customisation could be applied without the risks of investing in machinery, which is more appropriate for the UK context, as explained in chapters 4 and 5.

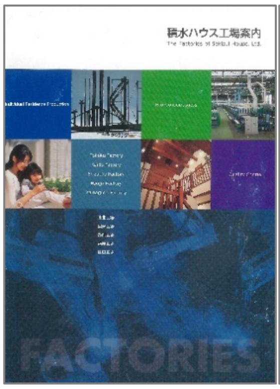
Carbon Dynamic turnover represents 0.02% of Sekisui House and 10% of Scotframe. Carbon Dynamic is an example of how start-up and small companies could implement mass customisation, as established companies hardly modify their business model.

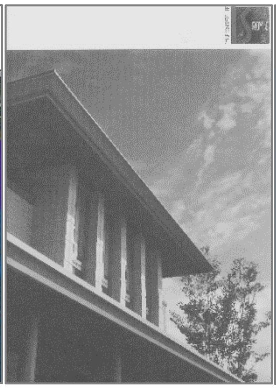
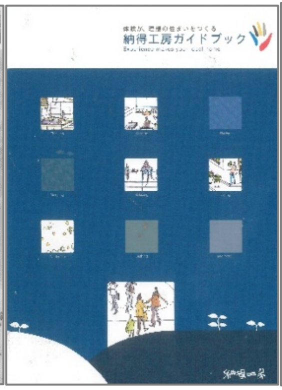
The Japanese scenario

Sekisui House

Brochures, guides and catalogues

Sekisui House supports its customers through the design decision-making and buying process with multiple and diverse types of brochures, guides and catalogues. The material provided by Sekisui House is highly informative and oriented to the general public. These are designed to inform the customer about the benefits of the multiple features or plan arrangements and how these relate to their lifestyle. The brochures and guides are illustrated with diagrams and graphics and supported with narratives of previous customers. The following images are examples of the different printed documents provided to Sekisui's House customers. The first is a brochure that describes Sekisui's House manufacturing capacity and production process (Fig. 192). The second is a material brochure provided to customers interested in houses with steel frame and concrete panels (Fig. 193). The third is a guide for an information centre, which includes maps and a description of the facilities (Fig. 194). The last is a guide for a housing park, which includes a map and description of the prototypes built (Fig. 195).



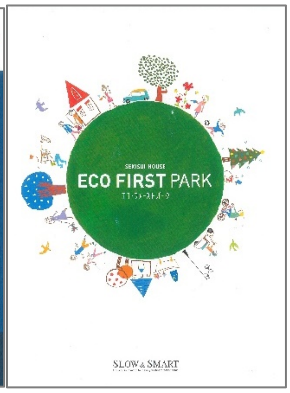


Figure 192. (left). Sekisui's House factories brochure. Figure 193. (middle left). 'Dyne Concrete' brochure of Sekisui House design line. Figure 194. (middle right). Guide of Sekisui's House 'House Creation Experience Museum' information centre. Figure 195. Guide of Sekisui's House 'Eco First Park' housing park adjacent to Kanto's factory (from Material collected in fieldwork visit to Sekisui House in May 2017).

The factory brochure is descriptive about the production process and manufacturing capacity of Sekisui House. It informs about the scale and capacity of Sekisui House but does not provide information about the customisation and selling processes. The material brochure is an informative brochure given to those customers that show a tendency to select a specific design line; which in this case consists of luxury models built with concrete panels and steel structure, named as 'Dyne Concrete'. Accordingly, the brochure's design and graphics are oriented to the top end market. Sekisui's House brochures include graphic representations of environmental qualities of the presented house models and its features. The following image shows a full page of the dyne Concrete brochure, highlighting the thermal graphics (Fig. 196).

Figure 196. Inside of Sekisui's House 'Dyne Concrete' brochure, highlighting environmental graphic information (from Material collected in fieldwork visit to Sekisui House in May 2017).

Sekisui House provides brochures and pamphlets to describe the architectural features that can be added to the houses. For example, Sekisui House gives the option to include 'Green Curtains', a hedge attached to the balconies of the houses. The Green Curtains brochure explains the benefits of having a hedge in terms of lifestyle and thermal comfort. The brochure includes 'quick response' (QR) codes where customers are linked to additional information about the hedges including manuals of how to maintain them, types of plants that can be used and its thermal benefits in relation to seasonal and diurnal changes. The following image shows the Green Curtain brochure extended on the top highlighting the environmental section, and the virtual extension of the brochure obtained from the QR code, highlighting an environmental diagram that explains the thermal benefits of the Green Curtain in a customer-friendly manner (Fig. 197).

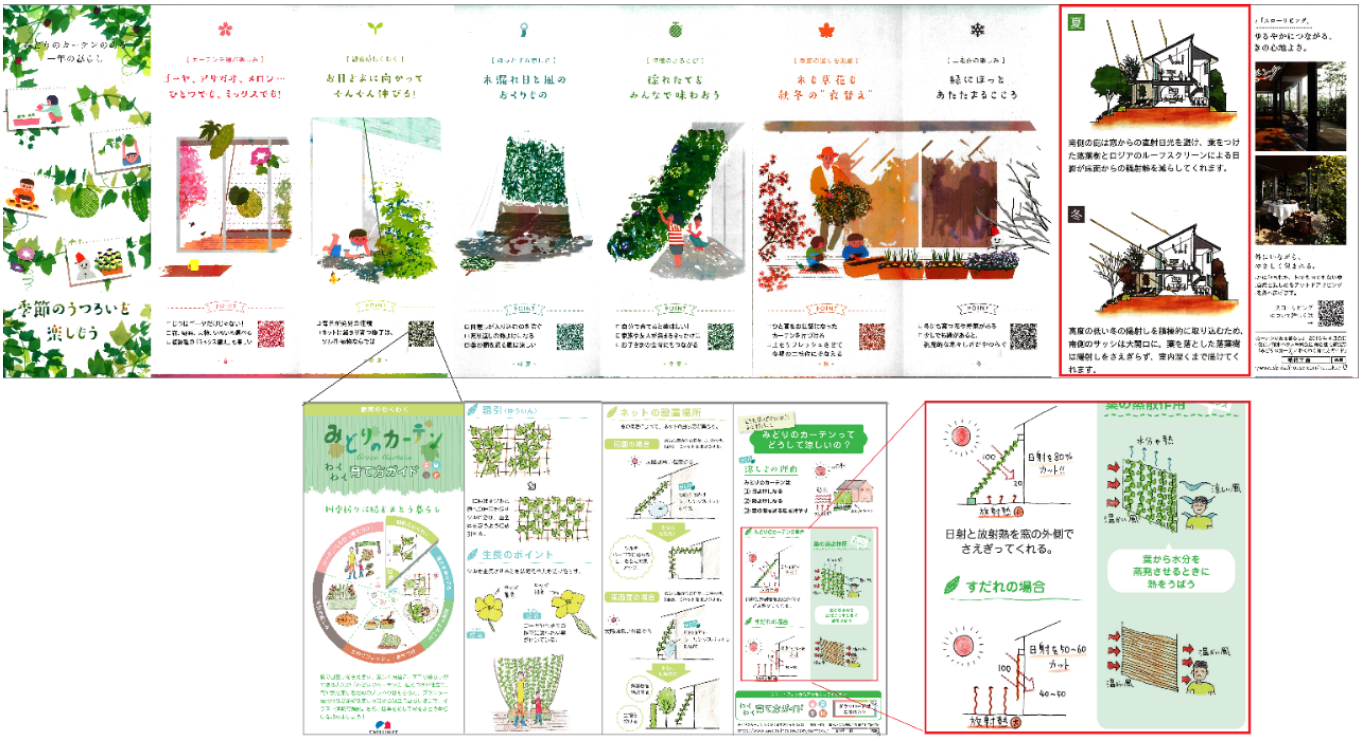


Figure 197. Green Curtain brochure and virtual extension obtained from QR code (by the Author from Material collected in fieldwork visit to Sekisui House in May 2017 and QR link from the brochure).

The information centre and housing parks brochures consist of guides for the customers and visitors; these include maps and information about the facilities. Sekisui House print multiple version of brochures with essentially the same information but formatted to accommodate different audiences. The following images are pages of Sekisui House guides of the same facility; the first one using simple illustrations and the second present plans, photographs and texts (Figs. 198 & 199).

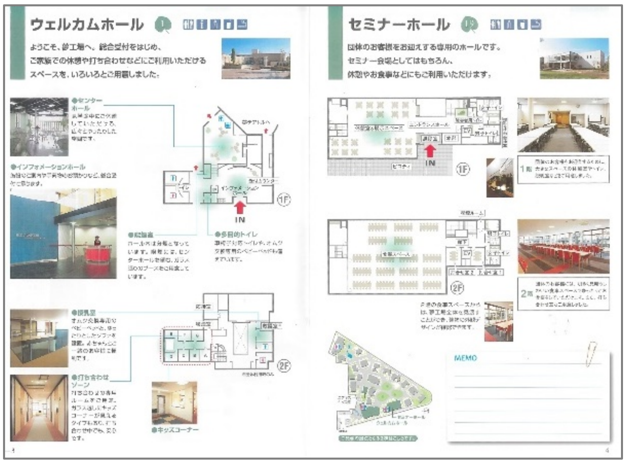


Figure 198. (left) Guide for ‘The Housing Dream Factory’ “childish” version. Figure 199. (right) Guide for ‘The Housing Dream Factory’ “adult” version (from Material collected in fieldwork visit to Sekisui House in May 2017).

Housing parks and showhouses

For Sekisui House, marketing and management represent 25% of their expenses; accordingly, they possess multiple showhouses and housing parks, as explained in chapter 5. Sekisui’s House scale allows them to have private housing parks, where visitors and customers can experience house models and architectural features in full scale and detail.

Sekisui’s House biggest private housing park, known as ‘The Housing Dream Factory’, is located in the Kanto facilities. It covers an area of 18,500m^2 and has 21 buildings, which include multiple showhouses, prototypes, technology showrooms, gardens and a customer centre with meeting areas and screening rooms. The following map shows the scale and arrangement of the different buildings in the housing park, accompanied by a translation table (Fig. 200).

Category	Facilities
Customer centres and information centres	1. Welcome Hall 2. Japanese-style features 3. Crime prevention building 4. 'Kids' related features **5. Environmental features (energy efficiency)** 19. Seminar Hall
'Lifestyle suggestion' pre-customised houses	6. Lighting features 7. The "Kobayashis' " house 8. The "Yamamotos' " house
Technology showrooms	9. 'Be Tech' building 10. Safety & earthquake

Category	Facilities
Construction and technology prototypes	11
Showhouses steelframe models	12, 13, 20, 21
Showhouses woodframe models	14, 15, 16, 17
'ShaMaison' showhouse (flats or condominiums)	18

Figure 200. Sekisui's House housing park in Kanto facilities (by the Author from Material collected in fieldwork visit Sekisui House in May 2017).

The customer centres are the facilities to accommodate visitors and customers, like a (4) children care. The customer centres are also places where customers and visitors are introduced to the company. The (1) welcoming hall has a reception, waiting room and screening area, like a small cinema. In it, visitors are projected with a short film unrelated to construction; and once this finishes, the screen retracts and transform into the entrance gate of the housing park. The following images show snaps of the film, the retracting of the projection screen and the entrance to the housing park (Fig. 201).

Figure 201. House sequence of screening film and entrance to housing park in the Welcome Hall of Sekisui's House Kanto facilities (arrangement of images by the Author from Schuester, 2007).

By the time of the fieldwork, the Housing Dream Factory park possessed eight active showhouses, which were exact representations of purchasable house models. These vary in size, style, equipment and structural material. Two (12 & 7) possed solar panels and were equipped with electrical appliances only (sun figure inscribed in a blue square). Two of them (12 & 21) were built with a patented steel structure against earthquakes 'Technology for peace of mind' (blue three-pointed leaf). Two of them (16 & 14) were built with a patented wooden structure against earthquakes, also known as 'Technology for peace of mind' (yellow seven-pointed leaf). One (13) was built with a steel structure 'beta version'. One (20) is a 'ShaMansion', which means a building with flats. Three of them (13, 16 & 14) were certified with the 'Good Design Award', which is given annually by the Japan Institute of Design Promotion. The following image shows the exterior of the eight showhouses in relation to the map of the park (Fig. 202).

Figure 202. Showhouses at the Housing Dream Factory park of Sekisui House (from Material collected in fieldwork visit Sekisui House in May 2017).

Two of the showrooms (7 & 8) were built and equipped to the preferences of supposed users, categorised as ‘Lifestyle tips’. These showhouses illustrate how different users would customise and arrange their houses regarding their particular wants and needs. The houses included furniture, clothing and decorations as if the users were inhabiting the houses. (7) The Kobayashis’ House is a prototype of a married couple with two children; while the (8) Yamamotos’ house provides the illusion of a matured couple living with a dog. The following images show features of the houses, their plan and a photograph of the “owners” (Figs. 203 & 204).

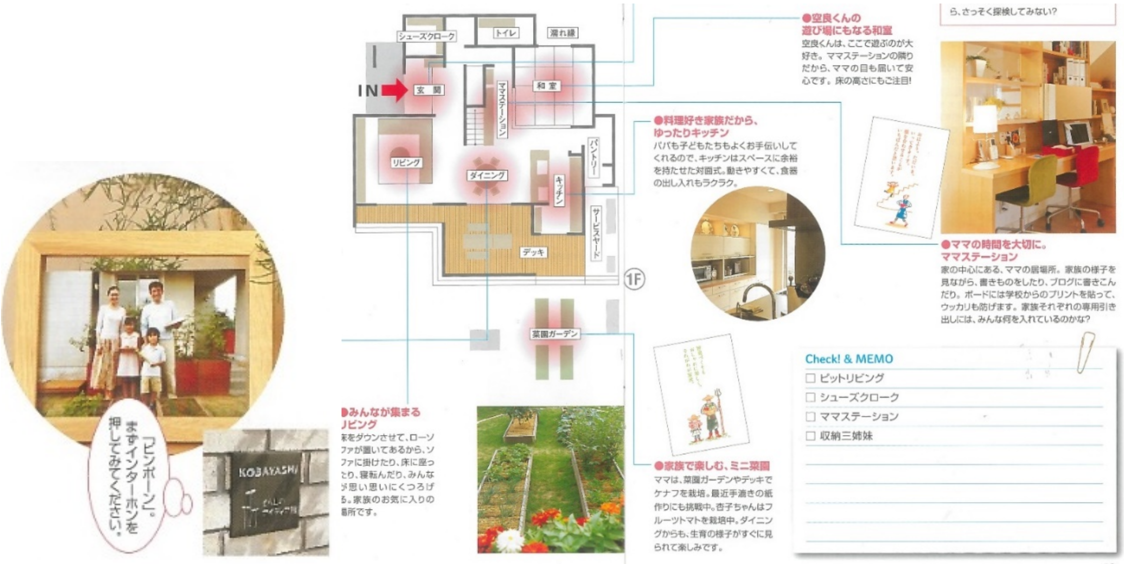


Figure 203. (7) Kobayashis' showhouse (Images from material collected in fieldwork visit to Sekisui House in May 2017).

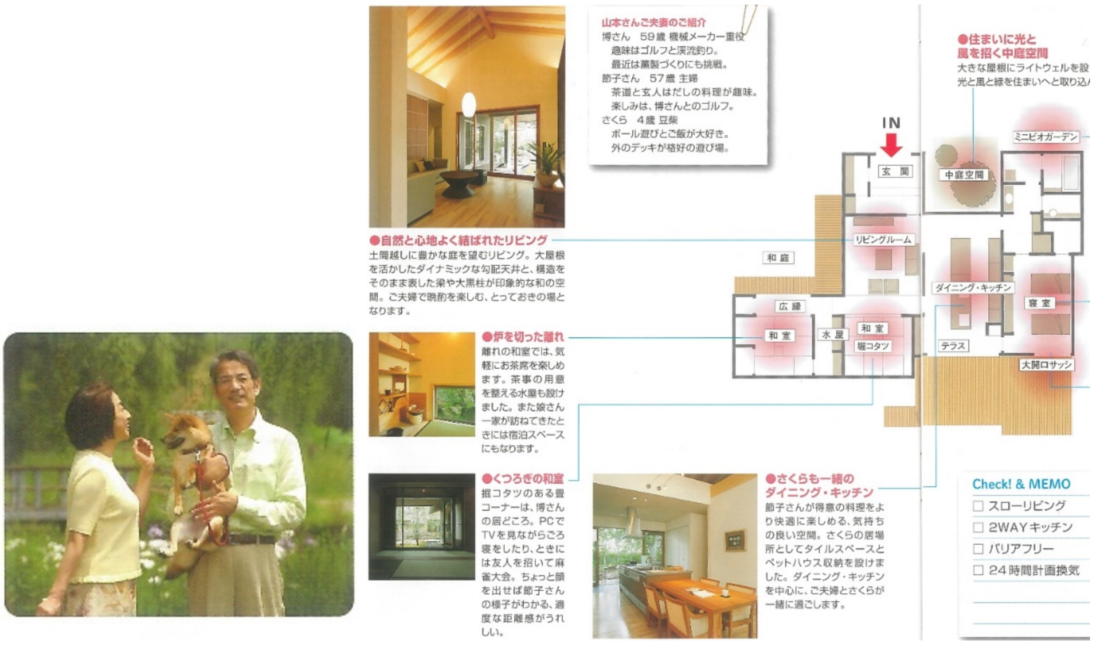


Figure 204. (7) Kobayashis' showhouse (Images from material collected in fieldwork visit to Sekisui House in May 2017).

The Housing Dream Factory park also has buildings that act as technology showrooms, which are extensions of the information centres and described later in this chapter.

The technology prototypes are these showhouses where Sekisui House show the innovations applied to new house models and ongoing research and development for future models. The 'Eco First' innovation park, located in Kanto's facilities of Sekisui House, has three house prototypes related to innovation in energy efficiency. The first showhouse is the newest zero energy model, known as 'Green First', which is currently available to purchase from Sekisui House. It is shaped to a design of the Sekisui catalogue and shows the most advanced energy-efficient features available. The following images show the Green First prototype exterior; a monitoring system visualised in tv screen showing the life energy consumption and production of renewables; and an automobile battery linked to the house electrical system, where electric cars can be charged from the electricity produced by the house solar panels or, in case of emergency, the house can take electricity from the car's battery (Figs. 205, 206 & 207).

Figure 205. Green First exterior.

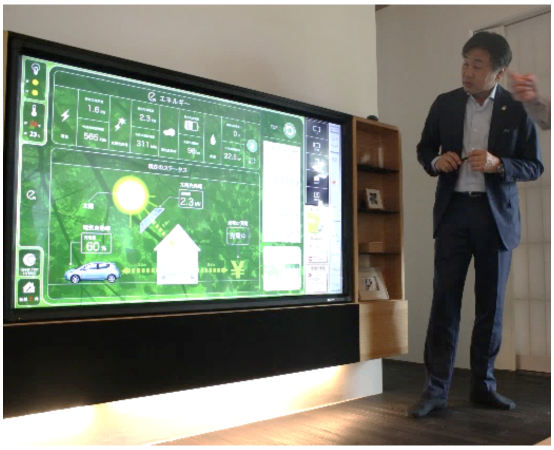


Figure 206. Monitoring system (Photographs by the Author from fieldwork visit to Sekisui House in May 2017).

Figure 207. Input/output battery for electric cars (Photograph provided by Norrie Smith from his visit to Sekisui House in May 2017)

The second showhouse is a prototype of a house that produces more energy through renewables than it consumes, it is named as ‘Zero Emission House’. It has a long pitched roof filled with solar panel tiles in one side and vegetation on the other side. It is ultra-airtight, with high insulation and triple glazing windows. Also, it displays prototypes of health equipment, as a compact electric movable chair device for elder or disabled people and a monitoring system that measures the inhabitants’ health conditions (Figs. 208, 209, 210 & 211).

Figure 208. Fig. XXX (left). Zero Emissions House roof with solar panel tiles.

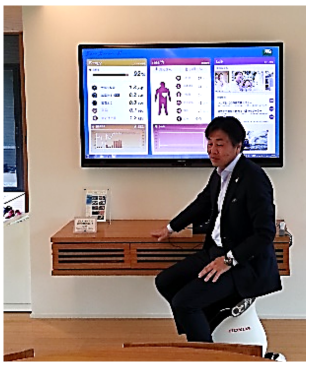


Figure 209. Fig. XXX (middle left). Energy and Health monitoring system, and movable electric chair device (Photographs provided by Norrie Smith from his visit to Sekisui House in May 2017).

Figure 210. Fig. XXX (middle right). Section model of triple windows and insulation material.

Figure 211. Green roof of Zero Emissions House. (Photographs by the Author from fieldwork visit to Sekisui House in May 2017).

The last showhouse in the Eco First innovation park is an experimental house of architectural features related to passive design and alternative living. The features in the display are not available for purchasing. This house is used as part of the research and development department of Sekisui House. The following images show the exterior of the prototype, fully glazed and naturally ventilated; furniture on wheels to allow multiple arrangements (sleeping in the balcony); and sensible opening systems for windows to open by the pressure of heat air (figs. 212, 213 & 214).

Figure 212. Fig. XXX (left). Exterior of the experimental house at the Eco First innovation park of Sekisui House (Photograph by the Author from fieldwork visit to Sekisui House in May 2017).

Figure 213. Fig. XXX (middle). Wheel on furniture (Photograph provided by Norrie Smith from his visit to Sekisui House in May 2017).

Figure 214. Passively opening system to release heat from the house (Photographs by the Author from fieldwork visit to Sekisui House in May 2017).

The information centres

The information centres are those buildings where Sekisui House display equipment that can be attached to the house. Sekisui House possesses large information centres that display all the potential equipment that houses can have, as explained in chapter 5. The information centres are big complexes attached close to the Sekisui House factories.

Customers visit the information centres several times during the selling process as these are also the offices and the design and selling centres. The information centre located in Kizugawa, near Kyoto, is one of the biggest of Sekisui House. The following image shows the scale of the information centre of Sekisui House in Kizugawa (Fig. 215).

Figure 215. Sekisui House information centre at Kizugawa (from Material collected in fieldwork visit Sekisui House in May 2017).

The first thing customers encounter when visiting the Kizugawa information centre is an area dedicated to the environment. In it, customers are explained about the relationship between housing, lifestyle and global warming, the importance of coexisting with nature, how construction materials are recycled and what renewables and insulation materials can provide to a house. In the relationship between housing and global warming section, Sekisui House informs the visitors about the amount of CO_2 released by houses with visual graphics and diagrams. They compare the average consumption of houses built in 1980s with the current models of Sekisui House. The following images show examples of how Sekisui House guide its visitors to the environmental area. The first image shows a comparison of energy consumption of appliances in a 1980s house (left) against appliances of a modern house (right) (Fig. 216). The second image shows the amount of CO_2 released by a household in the 1980s in the shape of a balloon (Fig. 217). The last image shows how Sekisui House show how different materials feel at different temperatures to explain visitors about their thermal properties (Fig. 218)


Figure 216. (left). Comparison of energy consumption of household appliances of the 1980s to nowadays. Figure 217. (middle). Visualisation of CO_2 emissions of a 1980s household. Figure 218. (right). Thermal sensation of different materials (images from material collected in fieldwork visit to Sekisui House in May 2017).

Then, visitors are guided to the technology showrooms where Sekisui House describes the technology used in their houses, in terms of construction systems, materials, anti-fire and anti-seismic structural capacity, and thermal and acoustic qualities. The information centres at the Kanto housing park have real scale models showing the structural frame of a full house, with sections showing the insulation materials and the inside of wall panels. Sekisui House also has demonstration rooms where they compare how different material reacts to the environment, in terms of transfer of light, heat and noise. The following images show examples of displays in the Kanto housing park technology showrooms. The first image shows a steel frame model (Fig. 219). The second shows a demonstration showroom comparing different type of glazing. Information, like infrared thermography and supportive data, is displayed on a monitor (Fig. 220). The third image shows a demonstration room where light penetration is measured according to different simulated orientations to explain how these affect the illumination and thermal comfort of a room (Fig. 221).

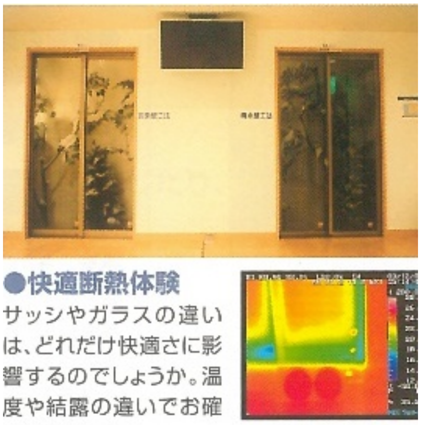


Figure 219. (left). Comparison of energy consumption of household appliances of the 1980s to nowadays.
Figure 220. (left) Visualisation of CO_2 emissions of a 1980s household.

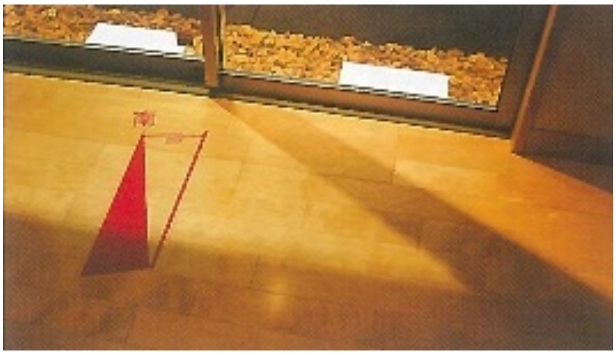


Figure 221. Thermal sensation of different materials (images from material collected in fieldwork visit to Sekisui House in May 2017).

The Sekisui's House Kanto housing park also posses an (5) environmental information centre. It consists of a building that displays potential features related to energy efficiency, including renewables, thermal windows, monitoring systems, energy cells, solar panels and batteries. All features are accompanied with related information, graphics and interactive mediums to allow the customer to understand the benefits of using energy-efficient systems. The following images show some of the energy efficiency features available as options (Figs. 222, 223, 224 & 225).


Figure 222. Fig. (top left). Explanatory board with information about the environmental effect of energy consumption in houses. Figure 223. (top right). Example of energy consumption of a traditional boiler and its effect to climate change.



Figure 224. Fig. XXX (bottom left). Different options for solar panel tiles accompanied by explanatory information. Figure 225. Fig. XXX (bottom middle). Display of energy cells with explanatory information. Figure 226. (bottom right). Display of monitoring systems (Images from material collected in fieldwork visit to Sekisui House in May 2017).

The information centres also work as co-design centres. Customers engaged in the purchasing process attend the information centres at different stages to agree on the design and characteristics of their house. The information centres have meeting rooms where clients discuss the design and are presented with virtual representation of their houses, as explained in chapter 5. Sekisui House supports the co-design process with human-scale models that allow the customers to decide based on experiences rather than only on visual representations. The following images show two examples of the design process through experience.

The first image shows two types of stairs that reach the same height and have the same number of steps but with different tread width (Fig. 227). The second image shows a stair where the tread width varies in every step (Fig. 228). The third image shows a living room with multiple lighting options, in terms of the type of lamps, lighting hue, tone and its location in the room (Fig. 229).

Figure 227. (left) & Figure 228. (right) Comparison of stairs by tread width.

Figure 229. Lighting showroom with two different lighting modes (Images from material collected in fieldwork visit to Sekisui House in May 2017).

The Sekisui House process of co-designing through experience includes aspects of security, design for ageing, storage dimensions, kitchen, toilets and bathrooms, mechanical systems, selection of renewables, equipment against disasters, Japanese furniture and garden. The following images show other interactive design processes. The first image shows a hallway with movable walls to get the spatial perception between the wall and the storage (Fig. 230). The second image shows a kitchen where furniture can move up, down and closer to each other. Customers measure themselves to determine the heights and lengths that adequate to their bodies (Fig. 231). Similar, there is a kitchen with special appliances for elder or people with disabilities, which also adjust in height and width. Sekisui House promotes all their customers to experience the showrooms using a wheelchair, or a limiting knee device understands how elder or disabled people would experience the house (Fig. 232). The last image shows an interactive simulator where customers can compare the energy consumption and CO_2 emissions and different combination of different appliances, including heating, ventilation and renewables systems (Fig. 233).

Figure 230. (left). Hallway and storage width dimensioning. Figure 231. (right). Kitchen adjusting showroom.

Figure 232. (left). Kitchen adjusting showroom for elder and disabled people. Figure 233. (right). Interactive energy and carbon simulation (Images from material collected in fieldwork visit to Sekisui House in May 2017).

Sekisui's House staff guide and keep track of the customer's preferences, and input them into the design outcome, which is later presented to the customers for their agreement. Therefore, the information centres are a crucial part of the co-design process in Sekisui House.

Sekisui Heim

Sekisui's Heim marketing is focused on simplifying and accelerating the selling process and demonstrating the quality of their products in terms of resistance to natural disasters and production of energy through renewables.

Brochure and catalogues

Sekisui Heim marketing and selling process centres on the selection of models from the catalogue. By the time of the fieldwork (2017), Sekisui Heim had 22 basic house models, 8 kitchen modules, 4 baths, 3 sinks and 2 WCs, which account for 4,224 different options. Sekisui Heim has additional features which increase the customisation options. The design process is designed through steps to avoid that the consumer gets overwhelmed by options. The following images present the catalogue of basic house models, the different options for bathrooms in terms of materials and sizes, and a calculation of variables (Figs. 234, 235 & Table 20).

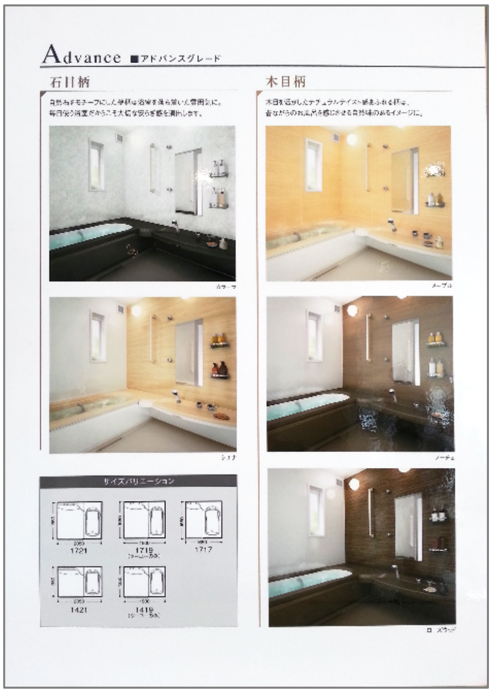


Figure 234. (left). Catalogue of basic models of Sekisui Heim in 2017. Figure 235. (right). Bathroom options (Images from photographs given by Norrie Smith from the visit to Sekisui Heim in May 2017).

Table 20. Possible variables of Sekisui Heim (by the Author with information from fieldwork visit to Sekisui Heim in May 2017).

	No. of variations	Aggregate options
Basic houses	22	22
Kitchens	8	176
Baths	4	704
Sinks	3	2112
WCs	2	4224

Accordingly, the brochures are designed to promote the selling of houses by model. The following images sections of a Sekisui Heim brochure dedicated to one of their models named 'Grand to You'. The first image is the brochure cover presenting a photograph of the house model (Fig. 237). The second image shows photographs of the interior of the house (Fig. 238). The third image shows the architectural plans of two house models (showhouse) with the price (Fig. 239). The last image promotes the visiting of Sekisui Heim factories and selling centres (Fig. 240).


Figure 236, Figure 237, Figure 238 & Figure 239. ‘Grand to You’ brochure of Sekisui Heim (from material collected from fieldwork visit to Sekisui Heim in May 2017).

Sekisui’s Heim brochure, as Sekisui House, have CQ codes that link customers to additional information about the house and the company. The diagram image shows the information displayed by the CQ code in the ‘Grand to You’ brochure. The image on the left side of the diagram is the physical brochure, which contains information about the production and purchasing process. The information linked to that page consists of a list of the showhouses available to visit in the Japanese territory. The customer can choose by location or by house model (Fig. 240).

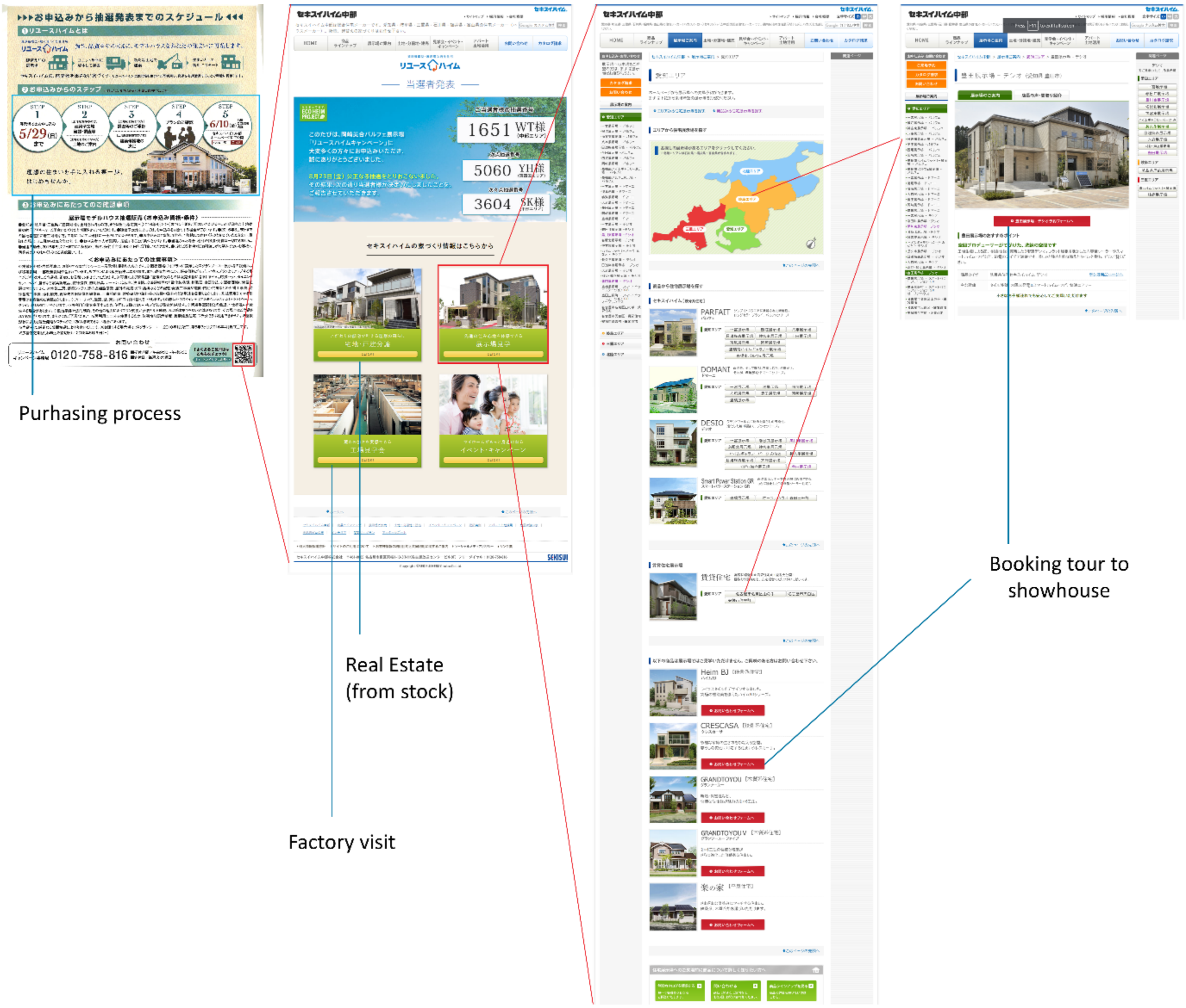


Figure 240. Booking process for Sekisui's Heim showhouses obtained from CQ link of a brochure (by the Author from material collected from fieldwork visit to Sekisui Heim in May 2017).

Sekisui's Heim brochures also provide financial advice to their customers. The following image shows a table of the potential cost increases on the purchasing of Sekisui Heim houses. In 2017, the interest rates in Japan were changing. This table presents the potential total cost of houses depending on the time of purchase and loan scheme (Fig. 241).

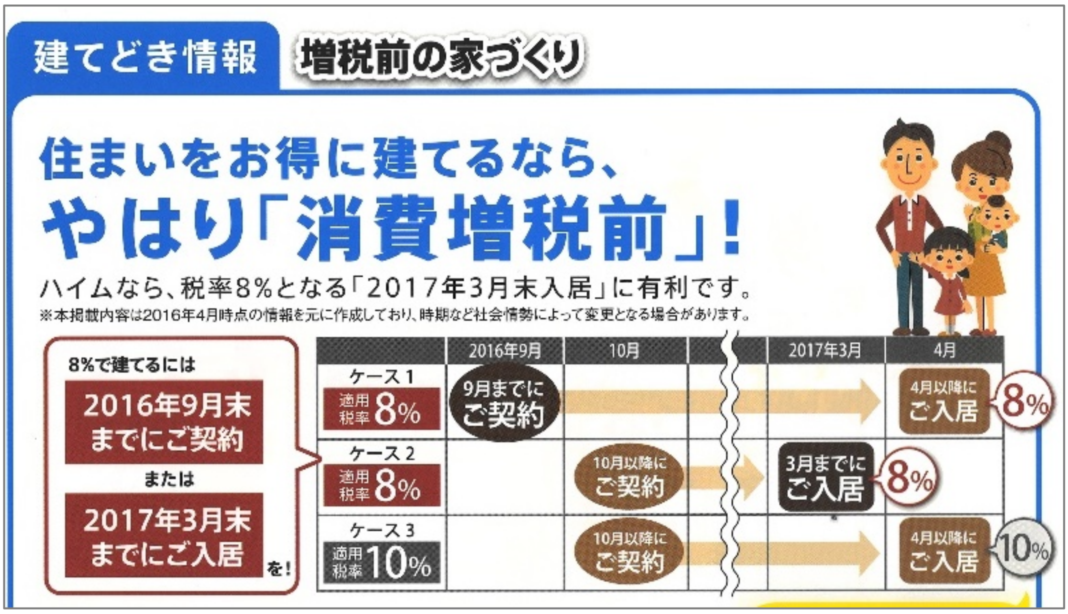


Figure 241. Table of potential costs for Sekisui Heim houses (from material collected from fieldwork visit to Sekisui Heim in May 2017).

Showhouses and selling centres

Sekisui Heim has multiple showhouses around the Japanese territory, including at least one adjacent to each of their factories. The showhouses are their main contacting point with their customers; all showhouses have at least one selling agent. Sekisui Heim does not possess sophisticated information centres as Sekisui House because their selling and design processes are different. However, they do have selling centres where customers can observe the different options of architectural features and materials. The following image shows a showhouse and a selling centre (orange building) located inside the Aichi plant of Sekisui Heim (Fig. 242).

Figure 242. Sekisui's Heim showhouse and selling centre (S-Square) located inside the Aichi plant (Images from photographs given by Norrie Smith from the visit to Sekisui Heim in May 2017).

The 'S-Square' selling centre in the Aichi plant consists of a two-storey building with multiple meeting rooms, a screening hall, material showrooms and display rooms of the kitchen and bathroom models. The following images show the S-Square selling centre plan, including images of each area (Fig. 243 & 244).

Figure 243 & Figure 244. Sekisui's Heim 'S-Square' selling centre brochure (from material collected from fieldwork visit to Sekisui Heim in May 2017).

Resistance to earthquakes is one of the strongest selling points of Sekisui Heim. They use earthquake simulators, not only to test their models but to market their houses. Customers and visitors are invited to *ride* a section of a house-unit mounted on a moving platform that simulates earthquakes. These include the structural frame, wall panels, roof, windows and doors; and screens displaying graphics of the simulated earthquake magnitude. The following image shows the earthquake simulator of Aichi plant (Fig. 245).

Figure 245. Sekisui's Heim earthquake simulator of Aichi plant (photograph given by Norrie Smith from the visit to Sekisui Heim in May 2017).

Daiwa House

Brochures and co-design

Daiwa House brochures are highly informative and are the core of its co-design process. The brochures not only describe the different options and features available, but they also provide data to assist the customer in the design decision-making, like surveys and interviews of previous customers. As an example, Daiwa has a specific brochure for customers interested in multigenerational living, which is common in Japan, as explained in chapter 4. This brochure starts by providing some useful data to generate confidence in customers about their decisions. The following image shows a survey of a Daiwa brochure with data about the customs of the Japanese population (Fig. 246).

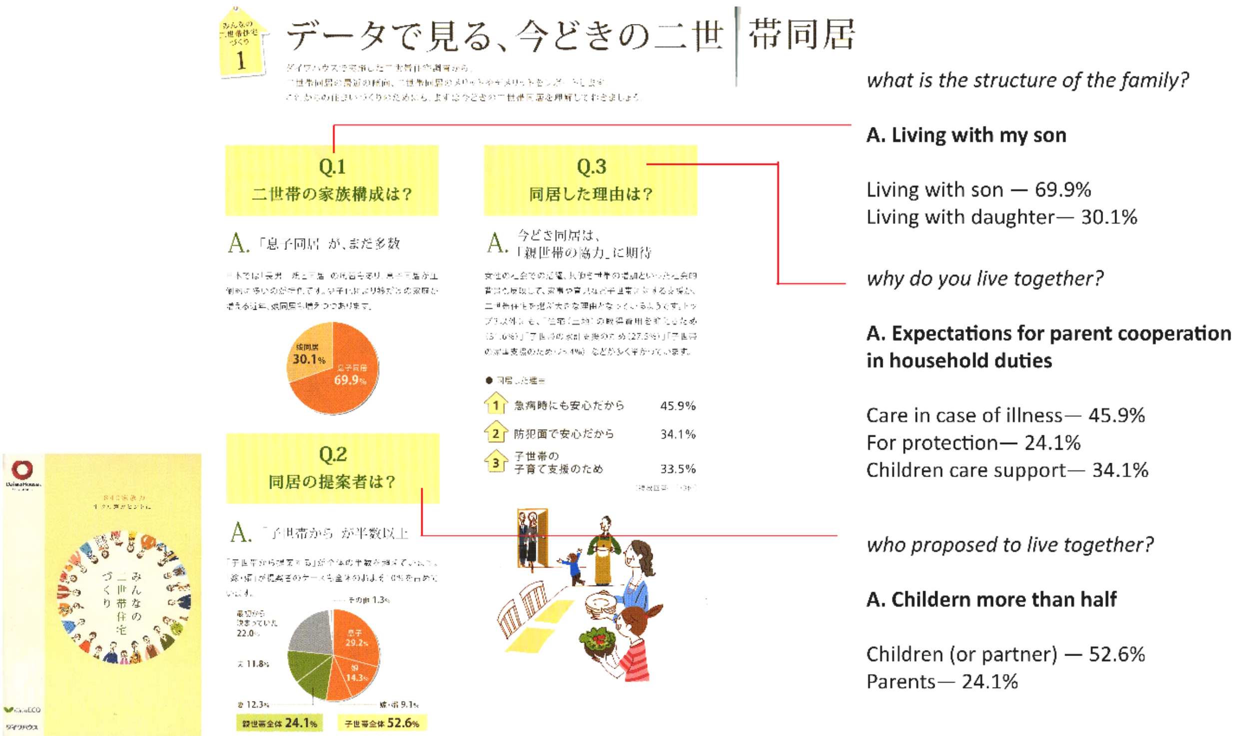
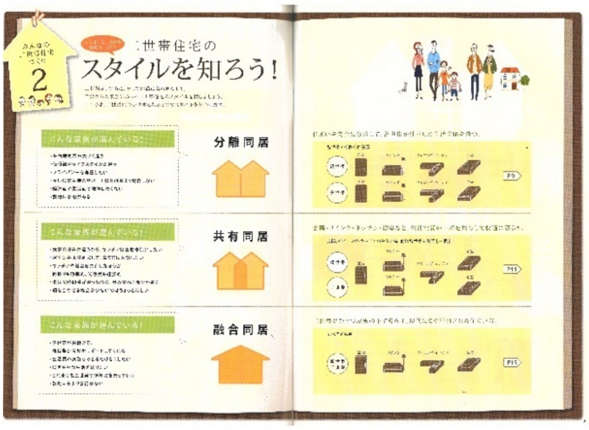


Figure 246. Daiwa's multigenerational house brochure cover in the left and translations in the right (by the Author from material collected from fieldwork visit to Daiwa House in May 2017).

Then, Daiwa presents three basic options for a multigenerational living for the customers to choose from. Each of the options are described through diagrams, graphics and references to previous customers experiences. The models differentiate on how the areas of the house are shared and arranged. The following images show the three multigenerational options described in the Daiwa brochure. Daiwa categorises the options as 'Separate Cohabitation' where the entrance, living, kitchen/dining and bathroom are separate; 'Joint Cohabitation' where the entrance and kitchen are together; and 'Integrated Cohabitation' where all spaces are integrated (Fig. 247). The second image provides information about what previous customers have selected. For example, it shows that 43.1% would ideally choose Separate Cohabitation and 28.9% Integrated Cohabitation, but eventually, only 16.5% opted for Separate Cohabitation and 55.9% selected to Integrated Cohabitation. It then, explains the reasons for those families to change their mind, like taxations or cost of living (Fig. 248).



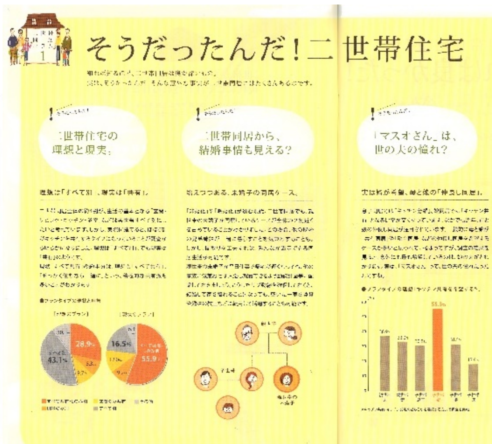


Figure 247 (left). Multigenerational basic options. Figure 248. (right). Supportive information related to the multigenerational living decision-making (from material collected from fieldwork visit to Daiwa House in May 2017).

The brochure continues by presenting architectural plans of the different co-habitation options and explain the differences in sharing against living separately. The following images show the diagrams and plans used in Daiwa's brochure. The diagrams in the left represent the percentage of the areas of each option, where green represents the private areas of the parents and pink the area of the children's family (Fig. 250). The diagrams in the right explain the differences between a single (bottom) or divided (top) entrance hall (Fig. 250).

Figure 249. (left). Multigenerational basic options represented with an architectural plan and percentage of areas.
Figure 250. (right). Differences between single and divided entrance hall represented in architectural plan (from material collected from fieldwork visit to Daiwa House in May 2017).

The brochure also explains how the architectural plans could adapt in the future to accommodate the rising needs of the family, like growing, shrinking or ageing. The following image shows a comparative scenario where the house areas could be adapted to changes. In the left, it shows the original family with shared living areas in the ground and first floor. In the right, it shows the grandparents living on the ground floor and the inclusion of more bedrooms (Fig. 251).

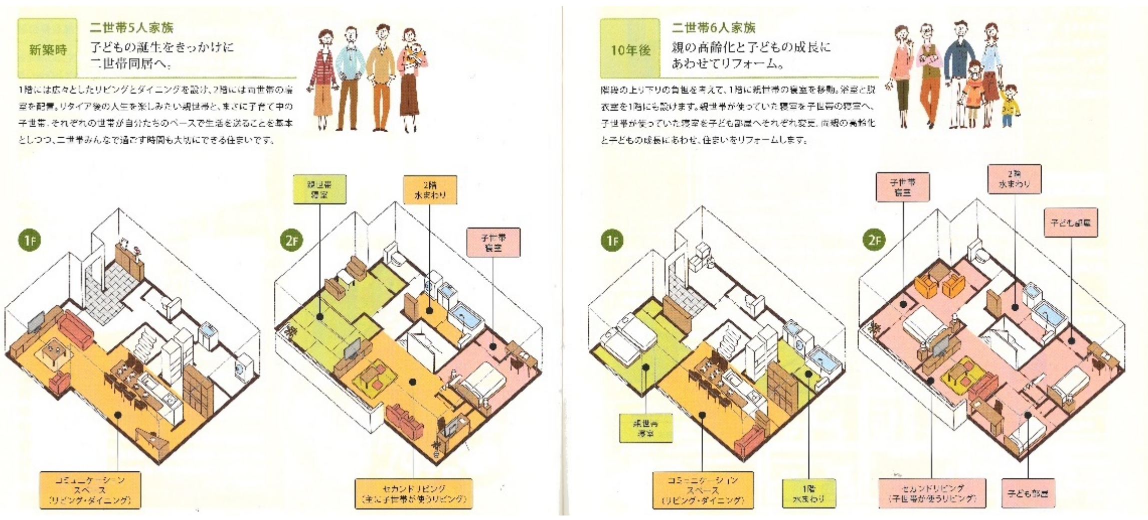


Figure 251. Future flexibility of a Daiwa house (from material collected from fieldwork visit to Daiwa House in May 2017).

Then, the brochure presents examples of how the co-habitation options fit into different styles and plots.

Daiwa's customers are not limited to the three basic options; they can select which areas they want to share and which ones they want private. The following images show different design alternatives. The first image represents the case where the family decided to share all areas except the living fitted into a square plot (Fig. 252). In the second case, the bathrooms and the living areas are separate, and the front is larger than the depth (fig. 253). The third case represents a family that decided to have a separate kitchen and living areas in a very narrow plot, resulting in a three-storey building (Fig. 254).

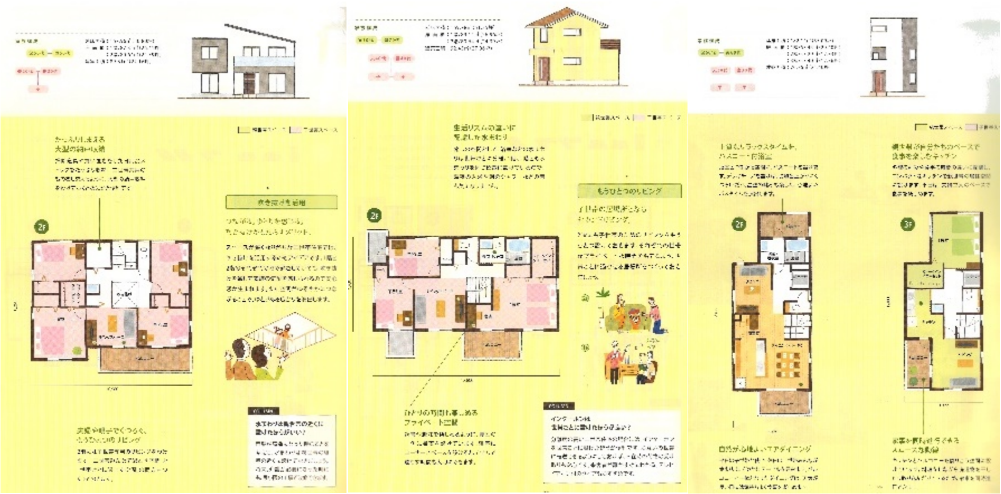


Figure 252. (left). Integrated Cohabitation in a square plot. Figure 253. (middle). Joint Cohabitation with a large front. Figure 254. (right). Separate Cohabitation in a narrow plot (from material collected from fieldwork visit to Daiwa House in May 2017).

The brochure finishes by presenting examples of houses designed and built by previous customers. It includes plans and photos of the inhabited houses and description of the families' experience. The following images show how these are displayed in the brochure. The first describes a family that opted for a Separate Cohabitation plan; and the second for a Joint Cohabitation (Figs. 255 & 256).

Figure 255. (left). Description of previous customers that chose a separate cohabitation plan. Figure 256. (right) Description of previous customers that chose a separate cohabitation plan (from material collected from fieldwork visit to Daiwa House in May 2017).

Daiwa co-design process extends to many details. As an example, Daiwa allows its customers to customise their houses according to their pets. The pet brochure, as the multigenerational brochure, guide the customers in the design decision-making process, includes data, photographs plans and experiences from previous customers. Daiwa not only offers various pet features and appliances that can be added to a house but suggests modifying the plan, selection of materials, type of doors and windows depending on the customer's pets[22]. The following images show the pet brochure, the different options and a catalogue of dogs and cats. The first image is the cover of the brochure (Fig. 257).

[22] The pet brochure is a clear example of the level of customisation available by Daiwa. The appendix includes a short story that explains the Daiwa's co-design process, named as 'the cat that designed his house' written by the Author.

The second image shows the special materials for specific types of pets, like a wooden floor if the customer has a hairy cat or carpet tiles for easy replacement in case getting dirty (Fig. 258). The last image consists of a guide of pet's breeds with its ideal weight. It allows customers to understand which type of pet they have and how the characteristics of each breed relate to the features offered by Daiwa (Fig. 259).

Figure 257. Fig. XXX (left). Daiwa's pet brochure cover. Figure 258. Fig. XXX (middle). Pet-related customisable features. Figure 259. (right). Pet catalogue (from material collected from fieldwork visit to Daiwa House in May 2017).

The pet brochure also includes different 'Plans' as suggestions to the customers, where the different features are applied to a supposed house plan. The following image shows one of the plans designed for small dogs, which includes flap doors, barriers, integrated sleeping areas and special cleaning areas (Fig. 260)

Figure 260. Suggested plan for small dogs on Daiwa's pet brochure (from material collected from fieldwork visit to Daiwa House in May 2017).

Information centres

Daiwa possesses large information centres. These are museum-like complexes where customers not only experience in first-hand the technologies offered by Daiwa but are presented with the history and values of the company. Daiwa's information centres include areas for research and development, also known as 'Techno Labs'; and showhouses. The 'Central Research Laboratory' is Daiwa's largest information centre. It counts with multiple showrooms, two museums, two Techno Labs, a seminar house and a showhouse. The showrooms (1) are those areas where customers experience the architectural features and technology is explained; similar to Sekisui House. The Techno Labs (4 & 5) are spaces closed for tours where Daiwa test and develop new technologies. The Seminar House (6) is an office building also closed for visitors. The following image shows the Central Research Laboratory (Fig. 260).

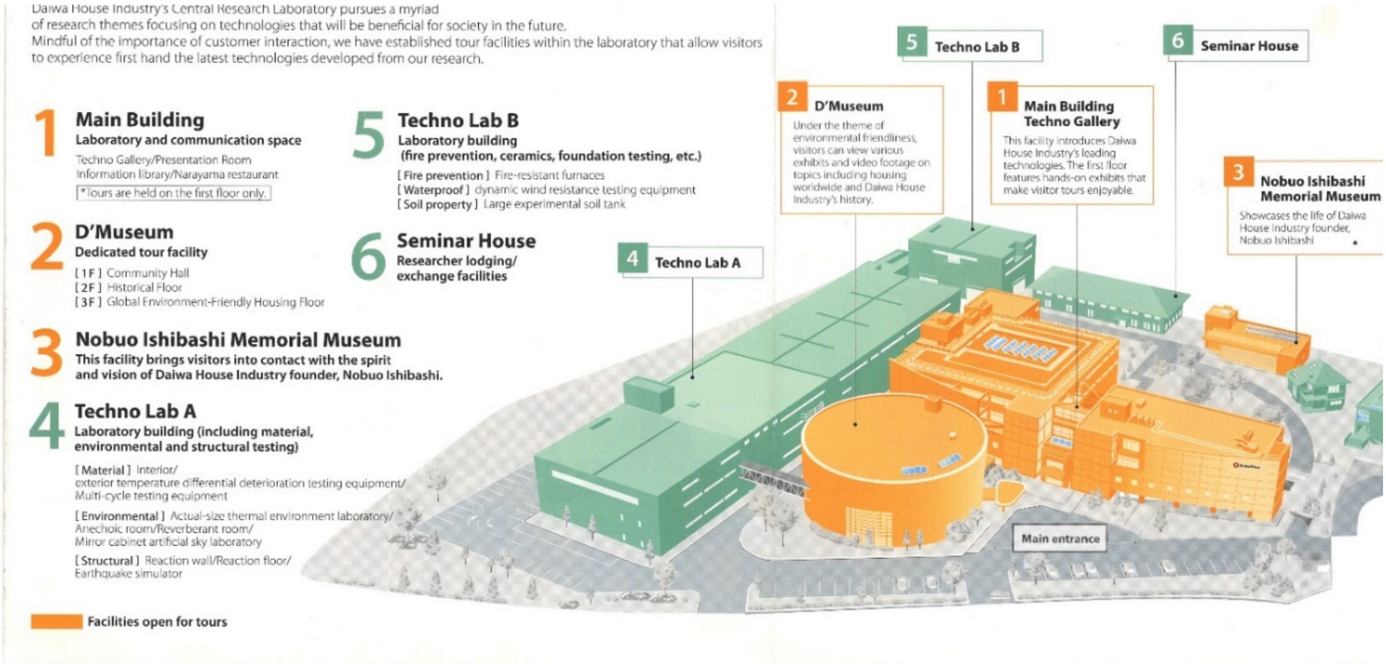


Figure 261. Daiwa's Central Research Laboratory (from material collected from fieldwork visit to Daiwa House in May 2017).

The museums are mainly dedicated to present the history and evolution of the Daiwa. The following images show part of the content shown in Daiwa's museum. The first image shows a timeline of Daiwa's history (Fig. 262). The second image shows an original house from the 1950s (Fig. 263). The third image shows one of the first computers used by Daiwa to produce CAD and CAM drawings (Fig. 264).

Figure 262. Fig. XXX (left). Daiwa's history timeline (photograph given by Norrie Smith from the visit to Sekisui Heim in May 2017). Figure 263. Fig. XXX (middle). Daiwa's first house model. Figure 264. (right). Daiwa's first CAD & CAM computer (photographs by the Author from fieldwork visit to Sekisui Heim in May 2017).

An example of the information in display is the timeline of house models. It shows the evolution of the houses built by Daiwa and the increase of the variety of materials and style. The following image presents the full timeline exposed in the Daiwa's Central Research Museum, which reads from right to left (Fig. 265).

Figure 265. Timeline of Daiwa's house models exposed in the Central Research Laboratory (by the Author from snapshots of video by Norrie Smith in the visit to Sekisui Heim in May 2017).

Daiwa dedicates a full floor of the museum to present models of vernacular housing typologies from around the world. It is entitled ‘Global Environment-Friendly Housing’ and is a marketing strategy particular of Daiwa House. In it, it is stated that the projects selected work as inspiration for all their new models, not only in terms of architecture but also engineering. The following images show Aiwa’s display of vernacular architecture models (Figs. 266, 267 & 268).

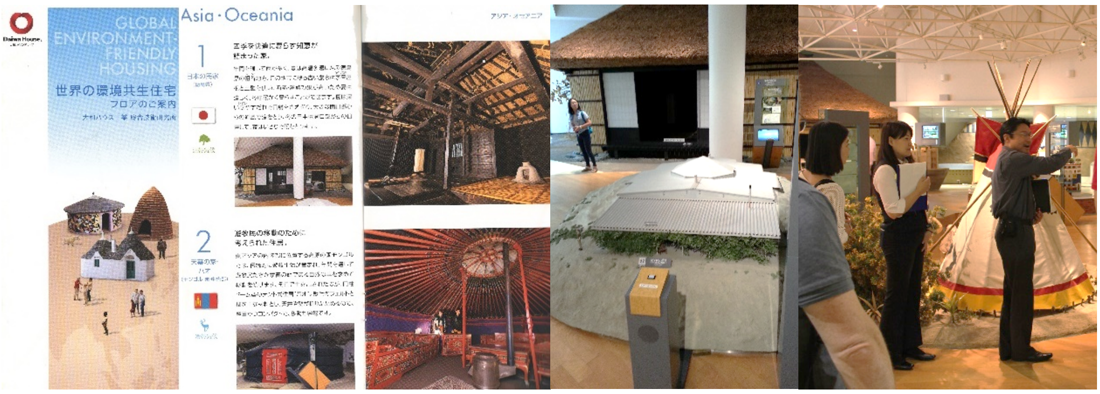


Figure 266. (left). Daiwa’s museum brochure (from material collected from fieldwork visit to Sekisui Heim in May 2017). Figure 267. (middle). Traditional Japanese Housing model (photograph provided by Norrie Smith visit Sekisui Heim in May 2017). Figure 268. (right). Tiipii model inside Daiwa’s museum (photograph by the Author from fieldwork visit to Sekisui Heim in May 2017).

The brochures and meetings with clients are the primary co-design strategy. Daiwa also uses life experiences to assist in the design decision-making process, but these are not as sophisticated as the ones used by Sekisui House. The following images show examples of the experiences and test rooms used to inform customers about the qualities of the architectural features on offer. The first image shows the testing of two different windows to feel the thermal performance of each option (Fig. 269). The second image shows a room for testing acoustic insulation (Fig. 270).

Figure 269. (left). Windows thermal comfort test. Figure 270. (right). Acoustic insulation test (from material collected from fieldwork visit to Sekisui Heim in May 2017).

The UK scenario

Scotframe

Catalogues and brochures

Catalogues and brochures are Scotframe's main selling and marketing mediums. Scotframe categorises their house models in four different catalogues, 'Homes Portfolio', 'Rural Homes Collection', 'Gaelic Homes Range' and 'Breton Exclusive'. Each catalogue is then subdivided into three or four subcategories regarding their typology; 'bungalow', '1.5 storeys', '1.75 storey' and '2 storeys'. Each category has between two and seventeen house models; where some have two or three different plan options. The following images present the covers of each of the Scotframe's house catalogues (Figs. 271, 272, 273 & 274).

Figure 271. Fig. XXX (left). Scotframe's Home Portfolio 2016. Figure 272. Fig. XXX (middle left). Scotframe's Rural Homes Collection 2016. Figure 273. Fig. XXX (middle right). Scotframe's Gaelic Homes Range 2016. Figure 274. (right). Scotframe's Briton Exclusive 2019 (from material collected from Scotrfame's website and fieldwork visit in March 2017).

The catalogues present the house models arranged by size with a virtually produced visualisation of the exterior of the house, the architectural plan and a table with the size of the house spaces. Some models include an additional visualisation showing a possible different option of plan or an architectural feature. The following images present different parts of the Scotframe's catalogues. The first image shows the list of house models included in the Homes Portfolio categorised by typology; purple stands for bungalows, green for 1 ½ and 1 ¾ storey houses, and blue for 2 storey houses (Fig. 276). The second image is the 'Fir' bungalow model of the Homes Portfolio with three possible plan arrangements (Fig. 277). The last image shows the 'Ptarmigan' house model in the Rural Homes Collection, which shows a potential variation in the front façade (Fig. 278).

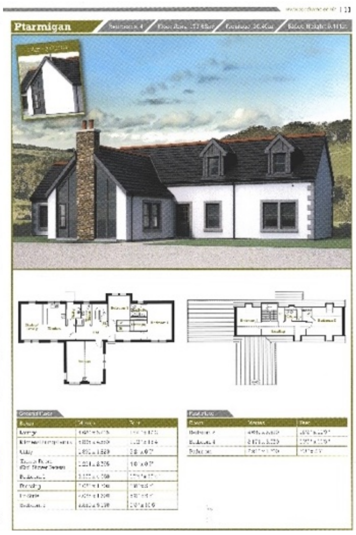


Figure 275. (left). Scotframe's Home Portfolio list of houses. Figure 276. (middle). Scotframe's Fir house model included in the Home Portfolio. Figure 277. (right). Scotframe's Ptarmigan house model included in the Rural Homes Collection (from material collected from fieldwork visit to Scotframe in March 2017).

Scotframe also provides their clients with additional brochures for selecting the type of doors, handles, skirtings and facings, stair spindles, newels, handrails and newel caps. The following images present the options available for Scotframe's houses. The first image shows twelve different options for internal doors (fig. 278). The second image shows handles and locks and the possible finishing treatments; polished chrome, satin chrome or polished brass (Fig. 279). The third image shows the five different profiles for skirting and facing, each in two possible dimensions and three possible finishes (Fig. 280). The last image shows the different options for stairs features, which include six options for spindles, three for newel posts and four types of newel caps; each in four possible timber finishes (Fig. 281).




Figure 278. (left). Internal door options from the Scotframe's Internal Doors brochure. Figure 279. (middle left). Handle and locks options from the Scotframe's Door Furniture & Finishes brochure. Figure 280. (middle right). Skirtings and facing options from the Scotframe's Door Furniture & Finishes brochure. Figure 281. (right). Staircase features from the Scotframe's Staircases brochure (from material collected from fieldwork visit to Scotframe in March 2017).

Some of the house models in the brochure include a note stating that the features shown in the illustration are not included in the price list but are available, if required, at additional cost. The 'Pear' model, for example, is illustrated with particular window and garage door styles, leaded glass to the external door, timber decorations in the façade and a 'French door', which are features not included in the standard model, but that can be added (Fig. 282).

Pear

4 bedrooms | FLOOR AREA: (Excl. GARAGE) 180.690m² (1945ft²) | FRONTAGE: 12.000m (39'4") | RIDGE HEIGHT: 7.412m (24'4")

ROOM	METRES	FEET	ROOM	METRES	FEET
Lounge	6.570 x 3.870	21'7" x 12'8"	En-Suite	2.470 x 1.700	8'1" x 5'7"
Dining	3.760 x 3.200	12'4" x 10'6"	Bedroom 2	3.870 x 2.870	12'8" x 9'5"
Kitchen	3.500 x 3.200	11'6" x 10'6"	Bedroom 3	3.600 x 2.740	11'10" x 9'0"
Utility	3.778 x 1.680	12'5" x 5'6"	Bedroom 4	3.090 x 2.870	10'2" x 9'5"
Shower	2.160 x 1.720	7'1" x 5'8"	Bathroom	2.470 x 2.040	8'1" x 6'8"
Family	4.700 x 3.590	15'5" x 11'9"	Garage	5.902 x 5.670	19'4" x 18'7"
Bedroom 1	4.000 x 3.500	13'1" x 11'6"			

*The approximate ridge heights shown, assume a finished floor to ground level of 400mm and are based on a roof pitch of 45° for the 1½ storey and 35° for the 1¾ storey.

The following features which are shown in the illustration are not included in our price list but are available, if required, at an additional cost.

These features are: The window and garage door styles, leaded glass to external door, all timber features and french door.

Figure 282. Pear house model showing potential add-ons (from material collected from fieldwork visit to Scotframe in March 2017).

Scotframe also allows their customers to choose one of the six construction specification options, which are related to airtightness and insulation. Scotframe provides ‘Price Guide & Kit Specification’ brochures to describe the differences and qualities of these specifications. The specification kits vary in type of frame panel (open or closed), thickness and type of insulation material (injected), the inclusion of vapour layer and type of windows (double or triple glazing). The six specifications consist of a different combination of these features. For example, the difference between the best and the second-best options rely on changing only the window type from double glazing to triple glazing. The following image shows the kit specification options explained through their properties, including thickness and U-values (Fig. 283).

	Bronze Open Panel	Silver Open Panel	Silver Closed Panel	Gold Closed Panel	Platinum Closed Panel	Platinum Plus Closed Panel
Ground Floor - by others						
Insulated Concrete Ground floor Designed / Supplied by others See assumed insulation thickness	60mm PU	65mm PU	65mm PU	120mm PU	160mm PU	160mm PU
U' Value W/m2K (below slab)	0.20	0.19	0.19	0.13	0.10	0.10
External Walls						
Breather membrane	Reflective	Reflective	Reflective	Reflective	Reflective	Reflective
OSB sheathing	9mm	9mm	9mm	9mm	9mm	9mm
Framing	140mm	140mm	90mm	140mm	235mm	235mm
Insulation	140mm Frametherm 40	140mm Frametherm 35	90mm PU	140mm PU	235mm PU	235mm PU
OSB Sheathing	Not applicable	Not applicable	9mm	9mm	9mm	9mm
Vapour control layer	Not applicable	Reflective	Reflective	Reflective	Reflective	Reflective
Service Void / Battens	Not applicable	35mm	35mm	35mm	35mm	35mm
Plasterboard	15mm TE vapourshield	15mm TE Plain	15mm TE Plain	15mm TE Plain	15mm TE Plain	15mm TE Plain
U' Value W/m2K	0.25	0.20	0.20	0.15	0.10	0.11
Roof -Horizontal Ceiling						
Insulation	280mm Frametherm 40	370mm Frametherm 40	370mm Frametherm 40	420mm Frametherm 40	560mm Frametherm 40	560mm Frametherm 40
U' Value W/m2K	0.15	0.11	0.11	0.10	0.08	0.08
Roof -Coomb/Sloping						
Insulation	140mm PU	170mm PU	170mm PU	170mm PU	170mm PU +25mm PU	170mm PU +25mm PU
Vapour control layer	Not applicable	Not applicable	Not applicable	Reflective	Reflective	Reflective
Service Void / Battens	Not applicable	Not applicable	Not applicable	35mm	35mm	35mm
Plasterboard	15mm TE vapourshield	15mm TE vapourshield	15mm TE vapourshield	15mm TE Plain	15mm TE Plain	15mm TE Plain
U' Value W/m2K -Tiled Roof	0.21	0.17	0.17	0.16	0.13	0.13
U' Value W/m2K -Slate Roof	0.19	0.16	0.16	0.14	0.12	0.12
Roof -Hanging post						
Insulation	140mm Frametherm 40	140mm Frametherm 35	140mm Frametherm 35	170mm PU	170mm +25mm PU	170mm +25mm PU
Vapour control layer	Not applicable	Not applicable	Not applicable	Reflective	Reflective	Reflective
Service Void / Battens	Not applicable	Not applicable	Not applicable	35mm	35mm	35mm
Plasterboard	15mm TE vapourshield	15mm TE vapourshield	15mm TE vapourshield	15mm TE Plain	15mm TE Plain	15mm TE Plain
U' Value W/m2K	0.28	0.26	0.26	0.16	0.13	0.13
External Joinery - W/m2K						
Windows (whole product)	1.40	1.40	1.40	1.40	1.40	0.90
External doorsets (average product)	1.40	1.40	1.40	1.40	1.40	1.40

Figure 283. Thermal Kit Specification table included in Scotframe's Homes Portfolio Price Guide & Kit Specification (from material collected from fieldwork visit to Scotframe in March 2017).

The Price Guide & Kit Specification brochure also includes a table of prices in relation to the house model and thermal specification options. The models are arranged by type, size, number of bedrooms and price. Each house catalogue has a Price Guide & Kit Specification brochure. The following image shows the house kit price list for the Homes Portfolio catalogue (Fig.284).

bungalows

BUNGALOWS House Name	Bedrooms	Floor Area M² (approx)	Bronze Open Panel	Silver Open Panel	Silver Closed Panel	Gold Closed Panel	Platinum Closed Panel	Platinum + Closed Panel
Acacia	2	66	£ 14,570	£ 15,195	£ 16,470	£ 17,360	£ 19,685	£ 20,815
Acer	3	76	£ 17,135	£ 17,825	£ 19,135	£ 20,145	£ 22,655	£ 24,405
Alder	3	88	£ 19,515	£ 20,270	£ 21,660	£ 22,725	£ 25,445	£ 27,080
Alder (+Garage/Utility)	3	93	£ 23,360	£ 24,415	£ 26,310	£ 27,765	£ 31,360	£ 33,130
Apple	3	91	£ 23,410	£ 24,420	£ 26,355	£ 27,845	£ 31,550	£ 33,340
Ash	3	94	£ 19,605	£ 20,410	£ 21,915	£ 23,065	£ 26,070	£ 27,960
Birch	3	107	£ 24,255	£ 25,135	£ 26,750	£ 27,990	£ 30,995	£ 33,000
Blackthorn (rear)	3	112	£ 23,425	£ 24,300	£ 25,890	£ 27,130	£ 30,150	£ 32,470
Blackthorn (front)	3	114	£ 24,820	£ 25,730	£ 27,355	£ 28,655	£ 32,070	£ 34,685
Cedar	3	113	£ 24,680	£ 25,625	£ 27,495	£ 28,825	£ 32,185	£ 34,485
Cedar (+ Garden area)	3	119	£ 28,515	£ 29,520	£ 31,465	£ 32,900	£ 36,555	£ 39,510
Cherry	3	121	£ 24,225	£ 25,195	£ 27,095	£ 28,445	£ 31,960	£ 34,285
Chestnut	3	126	£ 26,905	£ 28,085	£ 30,380	£ 32,190	£ 36,205	£ 38,345
Cypress	4	127	£ 28,790	£ 30,090	£ 32,635	£ 34,455	£ 38,995	£ 41,355
Fir (Option 1)	3	135	£ 29,725	£ 30,800	£ 32,755	£ 34,300	£ 38,060	£ 40,970
Fir (Option 2)	4	141	£ 31,665	£ 32,770	£ 34,775	£ 36,365	£ 40,260	£ 43,420
Fir (Option 3)	4	145	£ 32,065	£ 33,205	£ 35,260	£ 36,880	£ 40,865	£ 44,020
Holly	4	139	£ 30,975	£ 32,315	£ 34,910	£ 36,785	£ 41,655	£ 44,280
Larch (Split Level)	4	153	£ 32,975	£ 34,150	£ 36,260	£ 37,900	£ 42,075	£ 44,975
Magnolia	4	165	£ 37,450	£ 39,075	£ 42,235	£ 44,490	£ 50,255	£ 53,205
Mulberry (Split Level)	4	171	£ 35,985	£ 37,245	£ 39,635	£ 41,380	£ 45,815	£ 49,155
Poplar	4	197	£ 47,740	£ 49,605	£ 53,010	£ 55,585	£ 61,930	£ 66,325

1 ½ storey

1 ½ STOREY House Name	Bedrooms	Floor Area M² (approx)	Bronze Open Panel	Silver Open Panel	Silver Closed Panel	Gold Closed Panel	Platinum Closed Panel	Platinum + Closed Panel
Hawthorn	4	138	£ 33,175	£ 34,375	£ 36,085	£ 38,500	£ 42,220	£ 44,225
Hazel	4	139	£ 35,650	£ 36,845	£ 38,605	£ 41,365	£ 45,170	£ 47,460
Hemlock	4	138	£ 34,470	£ 35,665	£ 37,290	£ 39,685	£ 43,380	£ 45,795
Laburnum	4	150	£ 39,345	£ 41,055	£ 43,290	£ 46,970	£ 52,010	£ 54,990
Laurel	4	156	£ 36,070	£ 37,355	£ 39,265	£ 41,535	£ 45,405	£ 47,530
Pine	4	180	£ 40,790	£ 42,415	£ 44,535	£ 47,900	£ 52,555	£ 55,255
Plum	5	178	£ 37,115	£ 38,595	£ 41,100	£ 43,875	£ 48,550	£ 51,770
Redwood	4	209	£ 46,820	£ 48,285	£ 50,390	£ 52,895	£ 57,170	£ 61,530
Spruce	5	217	£ 51,400	£ 53,555	£ 56,725	£ 60,710	£ 67,150	£ 71,415
Walnut	5	237	£ 52,555	£ 54,565	£ 57,395	£ 61,335	£ 67,275	£ 70,915
Willow	5	247	£ 67,060	£ 69,585	£ 72,840	£ 77,860	£ 85,285	£ 90,910

1 ¾ storey

1 ¾ STOREY House Name	Bedrooms	Floor Area M² (approx)	Bronze Open Panel	Silver Open Panel	Silver Closed Panel	Gold Closed Panel	Platinum Closed Panel	Platinum + Closed Panel
Juniper	4	148	£ 39,645	£ 41,295	£ 45,505	£ 47,890	£ 53,560	£ 55,725
Maple (Option one)	5	186	£ 48,870	£ 50,365	£ 54,190	£ 56,430	£ 61,800	£ 66,075
Maple (Option two)	5	170	£ 38,935	£ 40,235	£ 43,800	£ 45,705	£ 50,345	£ 53,480
Orange	4	180	£ 49,550	£ 51,230	£ 55,205	£ 57,715	£ 63,790	£ 68,790
Pear	4	181	£ 49,020	£ 51,005	£ 55,170	£ 58,830	£ 65,175	£ 68,600
Rowan	5	211	£ 53,740	£ 55,875	£ 60,540	£ 64,480	£ 71,640	£ 75,060

two storey

2 STOREY House Name	Bedrooms	Floor Area M² (approx)	Bronze Open Panel	Silver Open Panel	Silver Closed Panel	Gold Closed Panel	Platinum Closed Panel	Platinum + Closed Panel
Aspen	3	98	£ 25,015	£ 26,360	£ 29,950	£ 31,940	£ 36,725	£ 38,395
Beech (Option one)	3	110	£ 29,170	£ 30,500	£ 34,105	£ 36,155	£ 41,340	£ 43,645
Beech (Option two)	4	129	£ 33,200	£ 34,780	£ 38,960	£ 41,480	£ 47,330	£ 49,910
Elder	4	139	£ 33,470	£ 34,915	£ 38,890	£ 41,080	£ 46,430	£ 49,550
Elm	4	134	£ 29,715	£ 30,855	£ 34,335	£ 36,120	£ 40,435	£ 43,595
Lime	4	158	£ 35,970	£ 37,245	£ 41,040	£ 43,045	£ 47,970	£ 52,170
Oak	5	176	£ 35,750	£ 37,120	£ 41,035	£ 43,150	£ 48,490	£ 52,030
Olive	5	193	£ 39,045	£ 40,785	£ 45,685	£ 48,260	£ 54,515	£ 57,800
Sycamore	5	219	£ 50,140	£ 52,145	£ 57,740	£ 60,755	£ 68,805	£ 73,360
Yew	5	317	£ 71,255	£ 73,945	£ 81,060	£ 85,060	£ 94,745	£ 100,905

Figure 284. Thermal Kit Specification table included in Scotframe's Homes Portfolio Price Guide & Kit Specification (from material collected from fieldwork visit to Scotframe in March 2017).

Material display

Scotframe's Cumbernauld facilities possess showrooms to display the different timber panels they produce and the possible features to include in the houses. The following images are photographs of the showrooms. The first photograph shows five different wall panels. The panels are organised as in the brochure, from left to right corresponding to their thermal qualities. The sample in the far left is an open panel with no insulation, while the sample in the far right corresponds to a closed panel with injected insulation with a U-value of 0.09 (Fig. 286). The second photograph shows Scotframe's showroom with samples of doors, windows, handles and staircase components (Fig. 287).


Figure 285. (left). Wall panel samples in Scotframe's Cumbernauld facilities. Figure 286. (right). Door and window samples in Scotframe's Cumbernauld facilities (photographs by the Author from fieldwork visit to Scotframe in March 2017).

Closed panels represent 60% of Scotframe's sales. Mike Cruickshank— sales director at Scotframe Timber Engineering— explains that customers understand the long-term value of better thermal performance and ensure that the preference for closed panels is rising. Cruickshank argues that customers are buying Scotframe's closed panel with injected insulation because these are inexpensive compared to on-site insulation processes of the same quality.

The features displayed in the showrooms relate to the options presented in the brochures. Scotframe's construction kit does not include kitchen or bathroom furniture, either mechanical systems, such as boilers, mechanical ventilation, heat pumps or renewables. These are tasks left to the contractor or self-builder.

Scotframe does not include renewables because there is no apparent market demand for them and does not add any value. Cruickshank (Personal Communication, March 2017) explains this as follows.

> *'Most clients don't really want renewables. ... They don't also like the fact that they need to maintain them. ... thermal heat pumps... it's far too complicated for them. ... Moreover, renewables are imported, so doesn't help the economy'.*

Carbon Dynamic

Catalogue and brochure

Carbon Dynamic's brochures focus on describing the company's values and finished projects. Carbon Dynamic possess a lodge brochure where they present four pre-design options. The lodges are presented with photographs of constructed projects, area and the estimated time of construction. The following images show the four design options available from Carbon Dynamic. For example, the first design, named 'Doe Lodge', has an area of $48m^2$, it is estimated to be delivered in twelve weeks and has a price on application. The four available designs have a price on application, which means that the clients need to contact the Carbon Dynamic to obtain a price (Figs. 287, 288, 289 & 290).

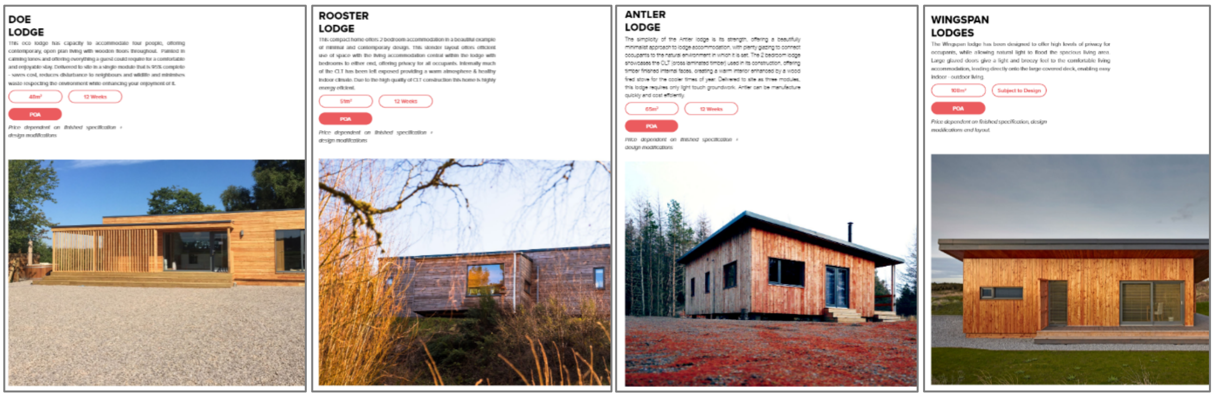
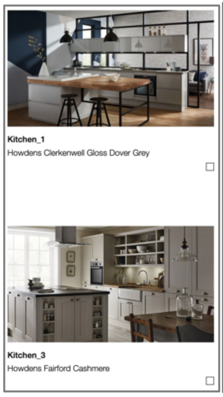


Figure 287. (left). Carbon Dynamic's Doe Lodge model. Figure 288. Fig. XXX (middle left). Carbon Dynamic's Rooster Lodge model. Figure 289. (middle right). Carbon Dynamic's Antler Lodge model. Figure 290. Carbon Dynamic's Wingspan Lodge model (from Carbon Dynamic Lodge brochure).

The brochure also presents a plan, an axonometric image and additional information about each of the lodge models. All the models are designed to have the same thermal capacity, with U-values of 0.145 for walls, 0.144 for the floor and 0.147 for the roof. Only one of the four models is presented with a flexible arrangement of spaces. The 'Wingspan Lodge' can include 2,3 or 4 bedrooms and 1,2 or 3 bathrooms. The following image presents the Wingspan lodge axonometric, plan and description (Fig. 291).

Figure 291. Carbon Dynamic's Wingspan Lodge axonometric, plan and description (from Carbon Dynamic Lodge brochure).

Carbon Dynamic also provides a 'Specification brochure' to select material colours, kitchen arrangement and even different models of equipment. The following images show examples of the options available. The first image shows two of the four different kitchen options (Fig. 292). The second image shows two of the three different roof material options, which in turn have three different colouring options (Fig. 293).



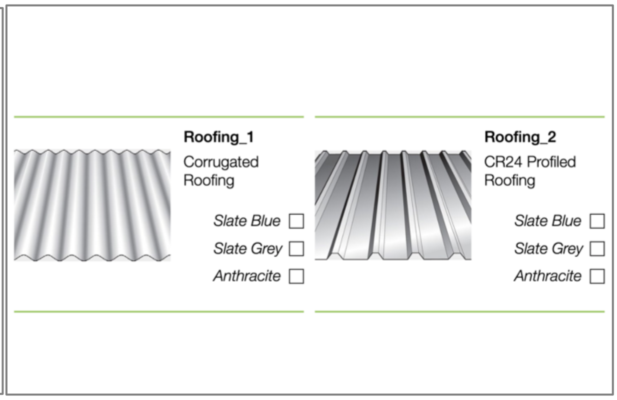


Figure 292. (left) Carbon Dynamic's kitchen options. Figure 293. (right). Carbon Dynamic's roof options (from Carbon Dynamic Specification brochure).

In terms of energy-related features, it is possible to specify the windows and heating system characteristics, but only from aesthetic qualities and not in terms of performance. The following images show Carbon Dynamic offer. The first image shows the possible window specifications varying in glass treatment but not in thermal performance; the options are limited to double glazing only (Fig. 294). The second image shows the different heating models available, which consist of the same model with different finish treatment (Fig. 295).

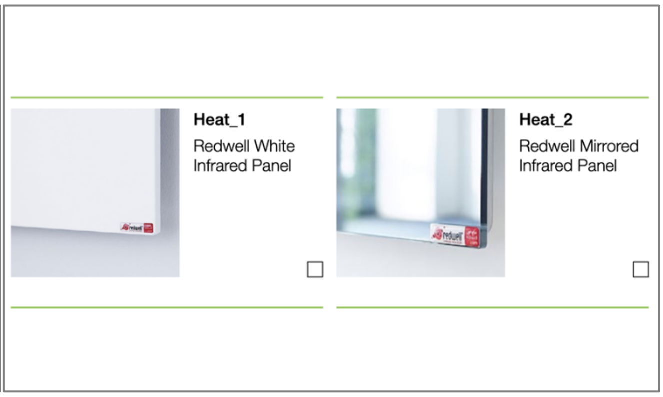
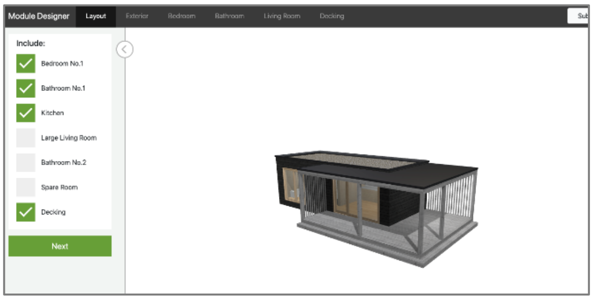


Figure 294. (left) Carbon Dynamic's kitchen options. Figure 295. (right). Carbon Dynamic's roof options (from Carbon Dynamic Specification brochure).

Virtual Module Designer

Carbon Dynamic possess a configurator tool that allows customers to select different options from a clicking box menu and configure a lodge to their preferences. This configurator tool is called ‘Module Designer’ and is available on their website and open to any person. It starts showing a virtual model that resembles the ‘Doe Lodge’ presented in the lodge catalogue. The model can be rotated, expanded and contracted. The configurator presents a list of different rooms that the user can tick or untick that will immediately modify the model. The following images show different configurations of the Module Designer. The first image shows the default configuration of the lodge, which includes a bedroom, a bathroom, a kitchen and the outside decking area (Fig. 296). The second image shows the model alterations, which add a large living room, a spare room, and an extra bathroom (Fig. 297).



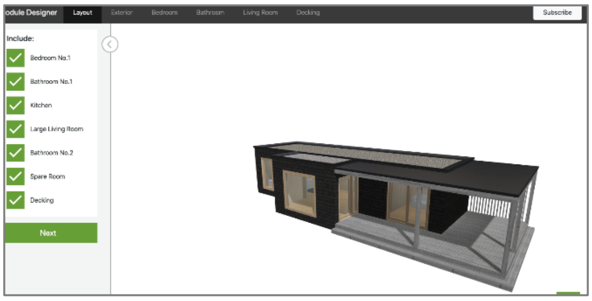


Figure 296. (left). Carbon Dynamic’s Module Designer default options. Figure 297. (right). Carbon Dynamic’s Module Designer with all potential rooms selected (by the Author from Carbon Dynamic website).

The configurator allows modifying the finishing materials, including roof treatment, veranda, decking, window frame and wall cladding. The following images show different options for materials. The first image shows the model with the default materials, which are ‘Ironwood Silver’ for the decking and veranda, ‘Charred Larch’ for the cladding, ‘Washed Pebbles’ for the roof and ‘Traditional Hardwood’ for the timber frames (Fig. 298). The second image shows how the model looks with alternative materials, like ‘Natural Larch’ for the cladding and ‘Sedum Planting’ for the roof (Fig. 299).

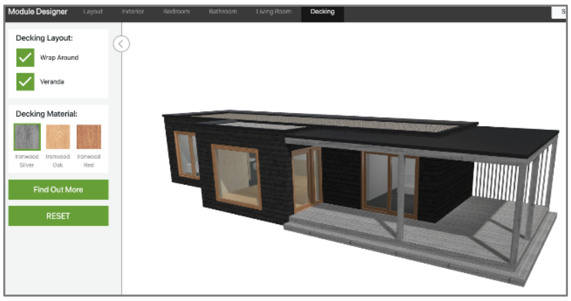
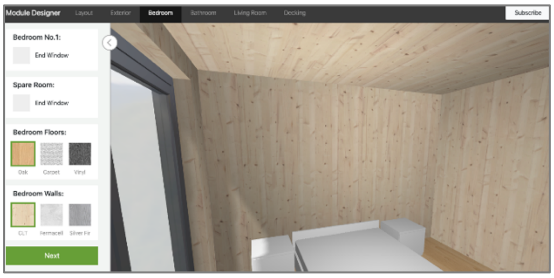


Figure 298. (left). Carbon Dynamic’s Module Designer default options. Figure 299. (right). Carbon Dynamic’s Module Designer with all potential rooms selected (by the Author from Carbon Dynamic website).

The configurator also allows to select the materials and make modifications to the interior of the lodges. It allows changing the positioning of windows in the bedrooms and the size of the bathroom. The following images show different configurations of the bedroom and the bathroom. The first two images show different materials in the bedroom (Figs. 300 & 301). The last two images show different arrangements of the bathroom; where the bathroom in the last image is larger than in the previous image (Fig. 302 & 303).



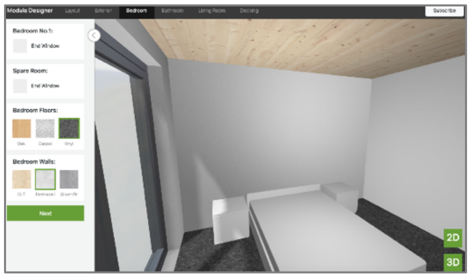


Figure 300. (top left) Module Designer bedroom default options. Figure 301. (top right) Module Designer bedroom with vinyl floor and 'Fermcell' walls instead of exposed CLT. Figure 302. (bottom left) Module Designer bathroom default options. Figure 303. (bottom right) Module Designer enlarged layout with alternative materials (by the Author from Carbon Dynamic website).

Carbon Dynamic virtual configuration is limited to materials and space arrangement. Mechanical systems or renewables are not included as options. In practice, however, Carbon Dynamic build houses that include renewables if the client requires them.

Comparison of selected companies: what are the Japanese doing differently?

This chapter described the different strategies used by the selected house manufacturers. The Japanese companies use more marketing and co-design strategies than UK companies; some of which are very sophisticated. Japanese house manufacturers invest heavily in setting multiple showhouses and put much emphasis on informing customers. The Japanese companies' co-design processes involve multiple design and measurement strategies; while the companies in the UK use fewer strategies, which emulate pattern books or bespoke architectural design processes. The following table shows a comparison of the marketing and design strategies used by the selected companies. The table is divided into five categories. ‘Capacity’ refers to the turnover and production volume of the companies. ‘Promotion’ refers to the marketing strategies used to invite customers to consume and increase the reputation of the company. ‘Experience’ refers to the facilities where customers and visitors can experience (see and touch) the houses and features offered by the companies. ‘Informing customers’ refers to those strategies used to provide customers with information and data that help them make informed decisions. ‘Co-design’ refers to those strategies used to obtain information from the customers that represent a change in the house design (Table 21).

Table 21. Marketing and design comparison of selected companies.

		Japan			UK		
		Sekisui House	**Sekisui Heim**	**Daiwa House**	**Robertson**	**Scotframe**	**Carbon Dynamic**
Capacity	*Turnover (M)*	£ 14,060	£ 7,388	£24,371	£ 565	£ 30	£ 3
	House production per year	13,600	10,500	9,300	1,000	1,500	<100
Promotion	*Marketing brochures*	X	X	X	-	X	X
	Portfolio	X	X	X	X	X	X
	Visitor centres ‘museums’	X	-	X	-	-	-
Experience	*Showhouses*	X	X	X	X	-	-
	Show villas / house parks	X	X	X	-	-	-
	Information centres	X	-	X	-	-	-
Informing customers	*Introduction to sustainability (information centres)*	X	-	X	-	-	-
	Technology showrooms	X	X	X	-	-	-
	Prototype showhouses	X	-	-	-	-	-
	Factory visits	X	X	-	-	X	X
	Brochures	X	X	X	-	X	X
	Virtual links	X	X	X	-	-	-
	Financial advice	X	X	X	-	-	-
	Personal salesman / architect	X	X	X	-	-	-
Co-design	*Catalogue of houses*	X	X	X	-	X	X
	Catalogue of features	X	X	X	-	X	X
	Online configurator	-	-	-	-	-	X
	Assisted design	X	X	X	-	X	X
	Experience measurements	X	-	-	-	-	-
	Previous customers brochure	X	-	X	-	-	-
	Product showroom	X	X	X	-	X	-

Japanese companies' promotion process not only involves the use of brochures and pamphlets; they possess visitor centres curated as museums open to the public used to explain the companies' history and values. Its purpose is to engage the visitors with the company and raise their reputation.

The Japanese companies invest heavily in setting and maintaining showhouses and build houses in show villas. Sekisui House also possesses various private housing parks adjacent to their factories. Sekisui House and Daiwa possess information centres where they display the architectural and technological features included in their houses. None of the UK companies selected use this strategy; which is a practice particular to the Japanese housing mass customisation context (Aitchison, 2018:95).

The main difference between the Japanese and UK companies is marked-out in how Japanese companies provide information to their customers. Japanese companies use multiple and very detailed, marketing strategies to transfer knowledge and do not restrict information strictly related to the characteristics of the houses and their features. The three Japanese companies provide sophisticated brochures that extend beyond the properties of the buildings. For example, Sekisui House provides gardening and cooking guidelines associated with the Green Curtains they sell. Sekisui Heim brochures detail the economic differences, in short, and long term, of buying a house regarding legislation changes. Daiwa brochures describe the socioeconomic tendencies related to housing.

The Japanese companies put emphasis on explaining the concepts of sustainability and environment and its relation to housing. The first exhibition of Sekisui's House and Daiwa's information centres focuses on sustainability. Sekisui House displays information on how households produce CO_2 emission; while Daiwa shows multiple vernacular housing examples and describes how these relate to sustainability.

All the selected companies (except Robertson) possess a matrix of options that allows a huge amount of house variations up for the decision of the customers. The difference among the companies of both countries relies on how Japanese companies guide the customers in the design decision-making process. They use different mediums to inform their customers about the benefits and possibilities available. Sekisui Heim demonstrates the quality of their structural systems using an earthquake simulator. Daiwa's multigenerational living brochure compares in detail the different plan option, including socioeconomic data, potential rearrangement of spaces for future needs and experience of previous customers.

Scotframe has 101 house models presented in four catalogues, each which needs to be specified from six different quality options, resulting in 606 house models directly presented and priced to the customers. Sekisui Heim, which has the manufacturing capacity to produce higher variability than Scotframe, presents only 22 basic models to avoid their customers to suffer from an *overchoice* situation. Simplifying the decision-making process, not only makes the process easier and faster for the customers but avoids customers dropping the purchase (Toffler, 1970:234; Tseng & Piller, 2010:5;

Salvador et al., 2019:2). Daiwa, in their multigenerational living brochure, only presents three basic options, which in reality encompasses hundreds of plan arrangements.

Sekisui House has a very particular co-design process based on measuring the customers' interaction with samples and mock-ups, instead of making them a choice from catalogues. Hence, the customers decision process is based on experience rather than assumptions. Sekisui House and Daiwa make their customers test the materials concerning noise and temperature; customers are invited to *feel* different windows exposed to the cold or to play loud instruments in a room covered with sound insulation material. Thus, customers can judge based on their experience and individual understanding of concepts, as noise or cold. Thermal and energy concepts represented in scientific measurements, like thermal transmittance units (W/m^2K) or decibels, are abstract and hard to grasp for a non-scientific audience. The experience co-design process extends to the selection of lighting systems, circulation dimensions and selection of materials.

Carbon Dynamic's module configurator allows customising a house module, visualising different plan arrangements and materials. However, these variables are unattached from useful information that could assist the customers in the design decision-making process, such as price or effect on thermal comfort. Japanese companies offer a personal consultation and design services, where they guide the customers with visualisation tools similar to the Carbon Dynamic's module configurator while providing them with useful information (Noguchi, 2004:28).

Japanese house manufacturers possess sophisticated navigation tools that allow users to visualise, modify, arrange and rearrange the design of their houses in accordance to the companies' solution space; and simultaneously process the information to carry out the production (Schoenwitz et al., 2012:203-204; Gann, 1996:446).

Paul Zipkin (2001:83) stated that there are four kinds of methods to obtain information from customers in the co-design process of mass customisation systems:

- *Identification (consultation)*
- *Customer's selections from menus or catalogues*
- *Reactions to prototypes*
- *Physical measurements*

Scotframe and Carbon Dynamic only cover the first two mass customisation marketing methods, as they do not possess information centres and their design process is based on catalogues. Sekisui Heim covers the first three methods as their marketing strategies centre in showhouses. Daiwa also covers the top three marketing methods as their co-design process centres on the use of brochures. Only Sekisui House covers all the methods suggested by Zipkin. Sekisui's House physical measurements are the most sophisticated co-design and marketing systems from the selected companies. Mass customisation does not require the use of the four methods; Daiwa House is recognised for providing higher customisation than Sekisui House.

Relation of marketing and co-designing with energy efficiency

Despite that the Japanese companies have more sophisticated marketing and co-design strategies than the companies in the UK is the lack of offer of sustainable features which limits the UK companies on delivering zero energy houses. From the companies selected, only the Japanese companies offer energy-efficient mechanical systems and renewables as customisable options, which are essential for conceiving zero energy. The following table indicates the sustainable features offered as customisable options from the selected companies (Table 22).

Table 22. Sustainable features offered as customisable options from the selected companies. *Housebuilders in the UK need to offer a 10-year warranty, where only the first two years cover defects and the rest consists of insurance on the structure of the house.

		Japan			UK		
		Sekisui House	**Sekisui Heim**	**Daiwa House**	**Robertson**	**Scotframe**	**Carbon Dynamic**
Fabric	*Structural material (steel or wood)*	X	X	-	-	-	-
	Insulation level	X	X	X	-	X	-
	Window U-value	X	X	X	-	X	-
	Doors U-value	X	X	X	-	-	-
Mechanical systems	*Heating systems*	X	X	X	-	-	-
	Ventilation systems	X	X	X	-	-	-
	Monitoring systems	X	X	X	-	-	-
	Energy cells	X	X	-	-	-	-
Renewables	*Heat pumps*	X	X	X	-	-	-
	Solar water heater	X	X	X	-	-	-
	Photovoltaics	X	X	X	-	-	-
Passive strategies	*Electric car connection*	X	X	X	-	-	-
	Green curtain	X	-	-	-	-	-
	Water recycling systems	X	X	-	-	-	-
Customer service	*Warranty*	X	X	X	*	*	*
	Maintenance	X	X	X	-	-	-
	Rearrangement	X	X	-	-	-	-
	Re-customisation	-	X	-	-	-	-

The main difference between the Japanese and UK companies is that the Japanese companies not only include mechanical systems, renewables and passive design features but that these are customisable. Sekisui's House customers can select if they want or not photovoltaic solar panels (PVs) in their houses. The solar panels can be customised in type, style, size and capacity. Sekisui House offers PVs in shaped as traditional ceramic tiles, which are not as efficient as the conventional PVs but are appealing to some customers. Sekisui House also offers as equipment related to the PVs as additional options, like different types of batteries and power cells, connection to electric cars, and monitoring systems. All these features are displayed in their showrooms and information centres and explained in their brochures. If the customers decide for one of these options, their personal salesman/architect shows them how much carbon, energy and money could be saved in short and long terms, and how would this affect the price and aesthetics of their house (Noguchi, 2013:169; Noguchi, 2004:28). Carbon Dynamic also installs PVs; however, they do not guide the customer in the decision process; neither offer this as an option.

Scotframe does not offer PVs, neither the installation of them. Scotframe declares that their clients do not *really* want PVs because they need to maintain them. The Japanese companies offer maintenance services, which customers can also customise in terms of length, coverage and cost, like health insurance. Thus, customers of the Japanese companies are confident to purchase mechanical systems and equipment difficult to maintain. Sekisui Heim and Sekisui House offer maintenance and upgrading of the equipment, which consists of repairing the mechanical systems or changing them for newer versions. Sekisui Heim also offers a 're-customisation' service, which consists of buying an old Sekisui Heim house as credit for a new house, including PVS and mechanical systems. Thus, their customers can consider the PVs as an investment, not only for the time of use but knowing they could get some money once the house reaches its end of life (Bock & Linner, 2015:123).

Scotframe also argues that energy-efficient equipment is not desirable because the users find them complicated to use. The Japanese companies provide multiple brochures guides and training to their customers regarding the equipment provided; as the Sekisui's House Green Curtain extensive and very detailed brochure.

The fabric quality (U-values) provided by the companies in the UK is as good, or even better than the Japanese offer. Carbon Dynamic standard fabric components have U-values of 0.14 W/m²K and windows with double glazing; however, these are standardised. Scotframe offer wall panels with U-values as low as 0.09 W/m²K, but do not provide renewables or mechanical systems. Therefore, only the Japanese companies can provide zero energy houses as part of their solution space and marketed options.

The marketing and co-design strategies and the post-sale services offered by the Japanese companies are an integral part of mass customisation. The promotion of sustainability encourages customers to opt for energy-efficient solutions. The demonstration rooms, brochures and personal guidance ensure that customers understand the environmental and long-term economic benefits of renewables and energy-efficient equipment. The brochures, guides, training, warranties and maintenance guarantee the correct use of the mechanics installed in the houses, which in the long term increase the customer's satisfaction and companies' reputation.

Japanese manufacturers benefit from selling energy-efficient features despite not producing them, such as PVs or energy cells (batteries), as these add value to their houses. Opposing to Scotframe's belief, including sustainable features increase the value of the products. As a matter of fact, the UK housing market is willing to pay a premium for sustainable houses (Rodrigues et al., 2012:206; Macmillan, 2006:260; Cuperus, 2003:299).

Mass customisation, only used as a strategy to increase variability, does not represent any advantage for the production of sustainable houses further than positioning a product in the market. The environmental benefits of mass customisation, as an integral production, marketing and informative strategy, consist of the increase in consumption of more sustainable designs and energy efficiency features and renewables.

Therefore, the relationship of mass customisation with zero energy housing relies on the companies' ability to promote and inform the benefits of zero energy houses, and instruct, guide and support the users on the use of the energy-efficient equipment; as much as on the capability of producing and including zero energy houses in their solution spaces.

Are Japanese marketing and co-design strategies suitable for the UK companies?

Some strategies used by the Japanese companies, like the information centres, museums, technology showrooms and housing parks, are out of budget of the UK companies; particularly of small and medium-sized companies as Scotframe and Carbon Dynamic. Technology showrooms are crucial to Japanese companies because resistance to natural disasters is one of their main selling points. However, that is not the case for the UK context.

Showhouses is a common practice in the UK housing market, which is a strategy not used by Scotframe or Carbon Dynamic. Other house manufacturers present in the UK market use showhouses to promote their products. As an example, 'Huf Haus'— a German house manufacturer— possess multiple showhouses in Europe including one in the UK (Rowlinson, 2016). The UK is not exempt from show villas, despite these not being a common practice. 'Scotland's Housing Expo 2010' is an example where small and medium contractors, developers and housing associations built over twenty house prototypes, which were then sold as houses (Hendry et al., 2011). Showhouses require investment that small companies, as Carbon Dynamic, might not be able to afford. Show villas, on the other hand, are suitable for housebuilders of all capacities. Show villas, however, are dependent on other organisations to happen.

The Japanese companies also use showrooms as an essential part of their marketing and co-design processes. Some of the Sekisui House showrooms are highly sophisticated and require huge display areas and use of technological equipment, like their kitchen and stairs measurement showrooms. Some other showrooms, as the window and flooring material thermal test, are more compact and do not require extensive infrastructure. Scotframe already possesses a showroom to display doors, windows and handrails, which could be expanded or adapted to resemble the Daiwa's or Sekisui's house showrooms.

Only Carbon Dynamic possess a virtual configurator openly available online. The Japanese companies use similar tools, but they use a salesman/architect to guide the customers through this process to ensure that they understand the implications, benefits and disadvantages of each decision. Japanese visualisation tools display information related to cost and environmental and energy impact; which is not present in Carbon Dynamic's virtual configurator (Noguchi et al., 2016:350-351).

All the companies selected use brochures and catalogues to promote their houses and show the options available. Even Robertson Homes provides catalogues of their houses in stock. However, only the Japanese companies use brochures as design guides. Daiwa's brochures are highly sophisticated and include multiple information techniques, like graphics, diagrams, sketches, architectural plans, design examples and narratives of previous customers. Daiwa is recognised for providing the most user-friendly selling process and the highest level of customisation, without using the sophisticated experience strategies used by Sekisui House (Bock & Linner, 2015:159). The implementation of brochures does not imply significant investments but require appropriate marketing, sociological and psychological research (Zipkin, 2001:87; Frederiks et al., 2014:1385).

Accordingly, some of the marketing and co-design strategies used by the Japanese companies appear suitable for the UK context and should impulse the consumption of sustainable housing. The companies in the UK should implement these strategies according to their financial capacity and marketing research (Salvador et al., 2019:1,24). Robertson, as a speculative developer, requires modifying their business model before implementing any of these strategies.

Conclusion

This chapter consisted of a description of the marketing, co-design and selling strategies of selected Japanese mass customisers and UK house manufacturers. It described these strategies through information, data and material collected in the fieldwork.

The way that UK and Japanese companies market their houses is very different. UK housebuilders are not capable of providing zero energy mass customisable houses because they do not have the adequate solution spaces nor integrated navigation tools to the production processes.

Companies such as Scotframe and Carbon Dynamic are investing in marketing oriented towards the customisation of their houses. However, their strategies are failing to achieve mass customisation because they lack market research or are disconnected from the real design and production processes. It can be summarised that three phenomena are limiting companies in the UK of achieving mass customisation.

1. *Companies do not invest in marketing and co-design processes*— Housebuilders in the UK do not invest in developing sophisticated selling strategies as the ones observed in Japan. Companies such as Robertson lack any co-design marketing strategy, including most mass housing developers. Investment rates of Japanese house manufacturers are as high as 25% of their profit. This percentage would not be enough to achieve the sophisticated selling strategies presented by some Japanese companies, like Sekisui's House selling centres and technology parks, but could be enough to develop highly informative brochures and even to build and maintain showhouses.

2. *Misunderstanding of the industrialised housing market*— Some companies are not producing houses adequate for the industrialised market niche. Scotframe already possesses a functional solution space and has opted to invest in the design of catalogues as a kind of navigation tool, which has proved to work for companies such as Sekisui Heim and Daiwa. However, the design of their houses does not follow adequate market research. Scotframe products resemble mass housing models, pitched roof bungalows rendered with stone with no integrated equipment or special features that industrially produced machinery can only produce, such as large openings or cantilevers. They are losing market share against other housing manufacturers that provide these features, like Carbon Dynamic, Rural design or Echo-Living.

Market research is fundamental to develop adequate solution spaces, navigation tools and informative material, such as brochures, guides and catalogues. Japanese companies are using the information gathered from market research directly in their marketing material. Daiwa, for example, integrates surveys and interviews to previous clients in their brochures to guide new customers in the design decision-making process. Sekisui House builds showhouses up to the specifications of previous customers as examples for new customers.

3. *Navigation tools are disconnected from the design and production processes*— Navigation tools are used for mere promotion of the company and are not used integral to the co-design and production processes, which is a missed opportunity. Companies like Carbon Dynamic have invested in developing interactive navigation tools and design configurators. However, different from the Japanese companies, Carbon Dynamic presents its configurator openly on their website. In contrast, Japanese companies use configurators as part of the co-design process and are always guided by an architect or salesman. Playing with the configurators does not guarantee the engagement of customers; actually, it disperse the audience as some customers would not understand what the different option will mean in terms of cost and performance.

It is important that navigation tools and configurators are linked to design and production processes. Not only to accelerate the communication between production and customer decision-making process; but to link costs and performance information to it. The decision-making process, particularly of energy-efficiency houses, directly relates to analysing environmental, performance and economic benefits in short and long terms. The more information provided to the clients the quicker they take decisions and more these are related to their wants and to better performance.

As stated in previous chapters, mass customisation does not mean zero energy. Housebuilders in the UK could modify their design and marketing strategies to achieve mass customisation; however, it could fail to deliver zero energy houses. There are three additional phenomena that are affecting the delivery of zero energy houses in companies of the UK.

4. *Not including sustainable features as options*— The more drastic difference between the observed companies is that companies in the UK offer very few or no sustainable features as customisable options. Companies like Scotframe simply overlook these features, and companies like Carbon Dynamic do not allow the clients to choose from different options. Scotframe is open to include equipment as solar panels in their houses if demanded by the client. However, clients that are not aware of these technologies will miss this opportunity. Carbon dynamic standards are designed to achieve high levels of airtightness and energy-efficiency. However, by limiting the decision capacity of their

clients they are limiting the possibility of someone investing higher to achieve zero energy standards or opt for sustainable options out of the ordinary.

It is in the interest of housebuilders to include as many additional equipment as possible, as they can add value to the equipment and increase the profit they get from each house. Also, it increases their satisfaction levels and reputation.

5. *Lack of description of the qualities of sustainable features*— House buyers, different from designers and engineers, have a different understanding of the capabilities and qualities of equipment and mechanical systems. Customers interested in including sustainable features usually retract considering them out of budget. It is a fact that including most energy-efficient equipment and renewables result in financial benefits in the long term. Japanese companies explain sustainable features extensively using different languages (scientific and non-scientific) to ensure that customers understand the benefits of opting for these. Scotframe explicitly declares that they stop including solar panels because customers did not know how to use them.

   Cultural contexts are different, and there is the possibility that the UK market has a lower attraction for sustainable features than Japan. However, the UK market is highly driven by financial conditions. Scotframe declares that their sales of insulated panels is increasing due their system has proved to be more affordable than on-site alternatives. It means that the UK market is looking for airtight products and that they customers could be driven to choose sustainable features if financial benefits are guaranteed.

6. *Lack of (equipment) maintenance*— Housebuilders in the UK do not include post sales services to their clients. Japanese companies provide long term post-occupancy maintenance services, as automobile companies. The contextual differences are driving Japanese companies to extend their services to compete in the market, which might not be the case of the UK. However, Japanese companies are using these services to engage customers in future purchases, which includes renovations. Japanese companies continuously improve the equipment of the houses, keeping them with the most energy efficient technology.

The marketing, co-design and selling strategies observed in the Japanese companies are an integral and essential part of mass customisation and for the delivery of zero energy houses. Sekisui House focuses on providing experiences to promote their products and also as a co-design strategy. Sekisui Heim main marketing investment consists of expanding and maintaining their showhouses. Sekisui Heim also provides the best post-sale service. Daiwa House focuses on producing clear and informative brochures to guide the customers in the design decision-making process.

The implementation of these strategies by the companies in the UK is needed to achieve mass customisation. However, it would not help them to sell zero energy houses if they do not include renewables and mechanical systems in their offer and solution space.

The relationship between the marketing, co-design and selling strategies of the Japanese mass customisers and zero energy houses relies on the companies' ability to inform and convince their customers about the benefits of consuming zero energy houses.

The marketing, co-design and selling strategies observed in the Japanese mass customisers could be implemented by UK house manufacturers but should follow market research and go in accordance with the companies' financial capacity.

Chapter 8

Conclusions

This thesis described the relationship that mass customisation has with the production and consumption of sustainable housing. It consisted of a comparative analysis of the Japanese and UK housebuilding contexts, including its production, marketing, and selling processes.

Japanese manufacturers are using mass customisation strategies to allow end-users to customise their houses in detail, including energy efficiency features; which has resulted in the lead of production of zero energy and zero carbon houses. Japanese house manufacturers effectively communicate the dwelling's operational energy costs and carbon impacts to their clients with sophisticated tools, visuals, catalogues, guides and models that allow customers to make informed choices.

Some housebuilders in the UK already possess the manufacturing capacity to produce highly airtight and insulated construction components; and production/assembly lines that allow variable outcomes, including the introduction of renewables if demanded by the client. However, the sustainable benefits observed in the Japanese context are not present in the UK. In order to increase the production of zero energy houses, UK manufacturers can implement some of the mass customisation co-design, marketing and selling strategies centred on sustainability and energy efficiency used by Japanese housebuilders.

The Japanese house market is a very good example of how manufacturing is related to housing; and how mass customisation can lead to sustainable housing practices. The current attempts to push industrialised processes in the UK housing practice have not provided house buyers with the benefits palpable in Japan—production consistency and efficiency, price certainty, high customisability, the inclusion of energy-efficient options, and more importantly a customer-oriented practice.

The investment in machinery and technology in the UK is not applied to solve systemic issues present in the housing phenomena, as on how mass customisation is used in Japan. Modern Methods of Construction and Prefabrication are strategies used in the UK only to solve construction constraints. Important elements of the housing practice, like the approach to final users, co-design processes, and business profitability, are overlooked. In contrast, these elements are carefully considered by Japanese housebuilders holistically with the production processes.

Japanese housebuilders have not always been oriented towards customer satisfaction. The main house manufacturers in Japan have been present for over fifty years. In early stages, Japanese housebuilders used industrial machinery to solve construction constraints related to the housing deficit, similar to how it is currently applied in the UK. The housing needs have drastically changed in Japan forcing them to modify their procurement processes. Japan has overcome their housing deficit, while there is little land available for development and this is not increasing its value. Consequently, they are using mass customisation as a strategy to survive in the housing market. Conditions in the UK are very different. The housebuilding business remains driven by housing deficit and land ownership. The government is pushing the use of industrialised methods of constructions to break this condition; however, these are merely used by housebuilders to reduce construction costs.

Housing conditions in Japan and the UK are far for being similar. Socio-economic contexts and legislation play an important role in housing in conjunction with how land affects its practice. It is factual that conditions in the UK are shifting and that there is a possibility that the current drastic housing inflation could lead to a housing bubble burst. Similar to what happened in Japan in the 1990s. In this scenario, housebuilders would need to shift towards customer-oriented practices to remain in business; or to prevent this phenomenon to occur. However, this is only a supposition, and these conditions might not be the same for the UK.

Nevertheless, housebuilders in the UK could adopt mass customisation and customer-oriented strategies to gain an advantage in the housing market, particularly in the rising niche of sustainable housing. The use of these practices is independent to the conditions imposed by land control. As an example, the successful implementation of energy-efficient equipment and sustainable features in the Japanese houses is unrelated to their legislation; it is merely a business strategy. In Japan, U-value regulations and carbon standards do not apply to most of the households (less than 300 square meters). They promote the use of sustainable features and have developed inclusive construction/production systems because it is good for their business. It allows them to increase the number of houses they sell per year, or to position themselves in a higher market range making more profit per unit. Both ways, it consists of a market strategy not exclusive of the housing practice; and therefore, feasible for the UK housing context. Prove of it, is that it is already present in the UK in other markets, like in the automobile industry.

Housebuilders in the UK would benefit from applying mass customisation strategies despite any shifting external factors. It is in their interest to apply fruitful business paradigms, particularly in the UK housing context dominated by the private industry.

Project-based sustainable housebuilding practices could particularly benefit from using mass customisation strategies to offer higher price and performance certainty; aspects that have proved to be a main barrier to compete with the open market. Also, housebuilders in the open market could apply mass customisation strategies to penetrate into the sustainable market niche. These companies already possess construction systems that provide them with cost certainty and production consistency. However, their lack of customer-approach, and hence their lack of design flexibility, runs in despair of sustainable principles, which are based on adapting to the particularities of users and environment.

Adopting mass customisation does require housebuilders to invert their current design and marketing paradigms, like Japanese housebuilders did after their land conditions changed. This paradigm shift involves the application of different management systems in procurement, production and marketing; and for some cases a rearrangement of their production processes. Positively, the UK already possesses a robust and flexible production capacity to produce construction components on demand. Modifying management, procurement and marketing systems requires investing less time and resources than investing on industrial machinery.

The construction industry has been sceptical about implementing mass customisation because it seems to belong to other practices and might not be feasible to the particularities of housing. However, mass customisation is a concept, or as it has been defined in multiple bibliography, as a paradigm. In theory, mass customisation belongs to all production practices and services; where housing is both. Mass customisation has been adopted firstly by other manufacturing markets because their supply chains are simpler, and its procurement involves less agents. It has proved to be an effective and profitable solution, and therefore, an increasing practice. Its application in the Japanese housing market has also proved its feasibility to the particularities of housing and construction. Therefore, mass customisation is feasible for the UK housing context and would bring market advantages to housebuilders.

This thesis proposes that housebuilders in the UK could use their existing production processes to achieve mass customisation. Investing in industrial machinery is not needed and would risk the finance conditions of the organisations. Manufacturers of construction components are already in possession of, and continuously investing on flexible manufacturing systems to amplify their market scope. Housebuilders can indirectly use these technologies to increase customisation in their construction systems. Carbon Dynamic and Muji are examples of housebuilders that take advantage of the manufacturing capacity of external manufacturers to achieve housing variability.

Rising technologies, machinery and communication systems are enriching manufacturing supply chains. CNC machinery and Lite industry equipment allows small and medium enterprises to produce flexible outcomes, like ‘Unto This Last’ and ‘Facit

Homes'. This production approach simplifies the procurement process and construction supply chains. Companies have direct control of their production processes and can modify it in accordance to the client desires. Mass customisation is achieved. Unfortunately, most energy-efficient mechanical systems, like MVHR, boilers, solar photovoltaics and monitoring systems are dependent on heavy industrial manufacturing. Manufacturers using CNC and Lite machinery need to include external manufacturers in their supply chains and ensure compatibility with external construction components to provide zero energy houses.

However, for the eventual application of mass customisation, efficient communication systems are required to communicate the customer's design decisions to all the manufacturers involved in a project. Housebuilders in the UK are already using digital management systems connected directly to machinery to control production from a centralised office and based on architectural and engineering drawings. Scotframe and Robertson are already using these management systems, as well as all the Japanese house manufacturers presented in this thesis. The difference is that communication systems of manufacturers in the UK are restricted to their production processes and not linked to all the agents involved in their supply chains. Housebuilders in the UK could use available communication technologies present in the construction industry, as BIM, to link their internal production management systems with their external providers and supply chains.

Efficient communication and agreement between housebuilders and manufacturers has proved to have higher importance than industrial capacity of companies in the UK.

Housebuilders in the UK can use components produced in countries with more sophisticated manufacturing capacities. Carbon Dynamic, for example, use CLT boards for the production of their houses. The UK does not possess a CLT manufacturer; however, Carbon Dynamic imports this from Austria, Germany or Portugal. These CLT providers follow the specifications provided by Carbon Dynamic (Dimensions, openings and thicknesses). Accordingly, housebuilders in the UK can use international manufacturers to cover for the deficiencies presented by the UK manufacturing capacity, including renewables, energy batteries or smart monitoring systems. Small and medium housing companies, as Carbon Dynamic, do not have the financial capacity to invest in heavy manufacturing machinery nor the production scale to justify its acquisition. Large housebuilding companies might be able to invest in machinery; however, the advantages this could bring them could be implemented via efficient communication and interconnection of supply chains with co-design systems. First, there is no certainty acquiring machinery would result in financial success, as it involves long payback processes in a volatile market such as housing. Housebuilders would prefer to invest in acquiring land rather than in machinery. Second, control over production could be equivalent if produced by external manufacturers, as Carbon Dynamic or Muji have proved.

Also, companies such as Carbon Dynamic are using virtual configurators to show potential clients possible design outcomes, including choosing finishing materials and architectural features as handrails. However, these configurator tools are disconnected from the real design, selling and production processes. These are only used as a marketing strategy to attract clients. Japanese mass customisers use similar configurators, not for marketing purposes, but in medium and late stages of the co-design process and only once the client has been engaged. Housebuilders in the UK need to smartly integrate their configurator tools to their production and co-design processes to achieve efficient mass customisation of energy-efficient features. These tools have high relation showing the financial and environmental benefits of energy-efficient equipment and renewables. Configurators could also be used to input the design-decisions directly to digital systems and to engineering plans, minimising mistakes and increasing precision.

It is important that manufacturers in the UK that pretend to enter the housebuilding market, or housebuilders that want to invest in manufacturing facilities, explore the housing market and understand which would be their position in it. Scotframe pretends to be a housebuilder, and is constantly extending their design catalogues; however, their production remains centred in manufacturing only construction components for other housing developers. Their houses are designed and produced to resemble the houses produced by developers; detached pitched roof houses rendered in stone. House buyers do not see any advantage in buying a house from Scotframe compared to the open market, the buying process is risky and more complicated as it involves acquiring a plot and hiring a contractor, and sometimes incompatible with mortgage systems. Established companies such as Huf Haus or Sekisui House produce houses that clearly differentiate from the open market. They provide branded design and special architectural features that attract customers.

Housing associations and developers that intend to invest in manufacturing have to understand how industrialising their procurement processes will affect their products. It is common that these housebuilders invest in machinery only to produce components independently and stop buying these from suppliers, hoping to result in production cost reduction in the long term. However, this approach remains in the mass housing context. Investments towards mass customisation and sustainability are those that alter their production processes to increase variability. Accordingly, their products and service will improve and most probably increase in cost. These companies need to design their management and marketing strategies in relation to these new standards and market niche; and most probably design their houses in accordance.

Taking the Japanese context into reference, producing ad-hoc houses for the industrialised market does not necessarily mean luxury houses. Some housebuilders do, like Sekisui House or Muji. However, most housebuilders produce average-looking houses, but highly equipped. The inclusion of integrated mechanical systems, renewables, pet appliances or any other features, is what distinguishes them from the open market; while providing certainty in performance, price and construction times what distinguish them from bespoke services. The inclusion of mechanical equipment highly relates to sustainability and energy-efficiency as are directly related to energy consumption and production.

Successful house manufacturers, not only in Japan, sell houses as products rather than just as houses. They place special attention to branding, detailing, development of unique-selling-points, customer service, marketing exposure, etc. Energy efficiency is the most recognisable sustainability tag from the customer perspective, and has proved to be a feature that house buyers expect when buying a house. It is in the interest of housebuilders to produce zero energy houses, and thus, distinguish their products from the open market and succeed as a business. Customisation is a must required by the nature of housing.

This thesis concludes that mass customisation is not only feasible for the UK housing context, but could be directly linked to the production increase of sustainable houses (zero energy). Housebuilders need to focus in sophisticating their design, marketing and communication systems based on appropriate market research.

This thesis answers to the established research questions as follows.

- ***What relationships can there be between Mass Customisation and the production and performance of Zero Energy houses?***

  Mass Customisation refers to the co-design processes of products and services that allow end-users to customise their products to certain limits that ensure stable but still flexible and responsive production processes. Zero energy houses, in turn, refers to a specific type of dwellings than generate more energy than they consume using energy-efficient strategies. The zero energy tag sets a clear boundary of possible designs, which can be used to set the limits of mass customisation options offered by a housebuilder. Therefore, a straightforward relationship among both concepts relies on the capacity of setting mass customisation solution spaces within zero energy design parameters.

Mass customisation also relates to zero energy as a strategy to cope with the market niche of zero energy houses. Mass customisation– as an integral aspect of the design process– allow housebuilders to adjust the design offers to the customers' wants, needs and budget; but more importantly, to different locations, climatic conditions, microclimates and orientations.

In addition, mass customisation— as a marketing strategy—encourages the consumption of zero energy houses; and consequently, raise their production.

Accordingly, this thesis encompasses the relationships between mass customisation and zero energy houses, by redefining the ZEMCH (Zero Energy Mass Custom Housing) term as,

… the mass customisation service that enables house-buyers to customise their dwellings, ensuring that these will generate enough energy on-site over a year to supply all expected on-site energy services.

Also as,

… the mass customisation process that enables the provision of zero energy dwellings through a defined solution space that runs in accordance to the company's production capacity; in which house-buyers can choose certain design aspects using choice navigation tools that present the benefits of the choices made.

… the service system designed to sell and market zero energy dwellings through mass customisation processes; in which the solution space is designed in accordance to the company's production capacity and uses choice navigation tools that facilitate house-buyers to customise their dwellings, restricting their choices to zero energy options.

In practice, the relationship that mass customisation has with the production of zero energy houses relies on extending the design options to the users, including energy-efficient equipment and renewables. Mass customisation housing systems increase the possibilities that people could find energy-efficient mechanical systems and renewables that satisfy their wants and needs. Mass customisation business principles establish that well informed customers are more willing to include additional features. An efficient application of mass customisation needs to include appropriate guides to educate customers about the benefits of sustainable features. The consumption of energy-efficient equipment is directly related to the market appreciation.

The creation of mass customisation solution spaces implies ensuring that the universe of components are compatible among them. Also, that the performance of all possible combinations could be measured and presented to the clients at the selling point decision-making process.

- ***What aspects of the Mass Customisation model of the Japanese housing context could be implemented in the UK?***

The Japanese particular socioeconomic conditions have caused them to possess production and manufacturing capacities that highly overcome housebuilders in the UK. Japan needs six times more new houses per year than the UK. Political and economic strategies taken in Japan after the Second World War boosted the establishment of the manufacturing industry in the housing sector. House manufacturers spinoff from large manufacturing companies since the 1960s, which still active today. In addition, Japan has scarce land available for development and legislation that encourages the fast reconstruction of its housing stock. Most new houses are built on the owners' land. Consequently, self-builders represent 75% of the housing market. Japanese house manufacturers have invested in manufacturing systems and technology to increase variation in their production lines to cope with the variable demand from self-builders.

The adoption of the manufacturing technology of Japanese house manufacturers is unsuitable for the UK context and jeopardise the survival of manufacturers in the UK. House manufacturers and manufacturers of housing components in the UK already possess the manufacturing capacity to produce customisable houses, despite not having the manufacturing and technology of Japanese manufacturers. Therefore, implementing the Japanese industrial capacity is not feasible to the UK context, it is not required to achieve mass customisation. If required, some of the industrial deficits can be covered by outsourcing components from other manufacturers in the UK or from abroad.

Japanese house manufacturers also possess sophisticated co-design, marketing and selling strategies, which in combination with their advanced manufacturing capacity, deliver mass customisation services. Some of these strategies, like information centres, museums, technology showrooms and housing parks, are out of budget of house manufacturers in the UK. Not all Japanese house manufacturers use these strategies and are still capable of providing zero energy houses through mass customisation. House manufacturers in the UK can achieve mass customisation by implementing the co-design, marketing and selling strategies that are compatible with their financial capacity.

The UK housing practice already uses some strategies observed in Japan, as the use of showhouses, brochures and catalogues. Other strategies, like the co-design process through experience and use of interactive showrooms, are suitable for the UK context, but most be implemented in relation to the companies' financial capacity.

It is important for companies in the UK to develop appropriate marketing research. Japanese companies, like Sekisui House, invest around 25% of their income in marketing. Housebuilders in the UK could analyse what could they achieve if they invest a similar portion of their income accordingly.

- ***How to implement Mass Customisation in the UK context to increase the production/consumption of zero energy houses in the UK context?***

Mass customisation requires the introduction of the end-user in the design and production processes. Most manufacturers in the UK are disconnected from the final selling process. Housebuilders interested in applying mass customisation have to ensure that their manufacturing, design and selling process are linked together.

The implementation of mass customisation requires the equal development of the three mass customisation capabilities– solution space, robust design and choice navigation. UK manufacturers already possess a robust capacity for producing customisable products and zero energy houses. However, they require to develop or improve their solution spaces and choice navigation tools to be capable of producing zero energy house through mass customisation processes.

The main differences between the co-design, marketing and selling processes of Japan and the UK consists on the ability of Japanese companies to include energy-efficient features as customisable options,, and possess solution spaces limited to zero energy models where they adequately inform and convince their customers about the benefits of opting for a zero energy house. Therefore, the relationship of mass customisation with zero energy housing relies on the companies' ability to promote and inform the benefits of zero energy houses, and instruct, guide and support the users on the use of the energy-efficient equipment.

The current co-design, marketing and selling processes of manufacturers in the UK lack of solution spaces limited to zero energy houses and choice navigation processes that convincingly inform about the benefits of opting for a zero energy house.

The development of zero energy solution spaces and informative choice navigation tools require market research to understand which strategies are appropriate for the UK context and the particular capabilities of each housebuilder. It is essential to include energy-efficient equipment and renewables in the solution space to be able to provide zero energy options.

There are multiple ways for housebuilders in the UK to implement mass customisation– innovative production management systems, instant design and communication systems within all their supply chains, interactive co-design strategies, and marketing strategies including brochures, catalogues, showhouses, information centres, etc. All of which needs to be implemented understanding their production capacity and a deep market research.

> This thesis does not provide a list of particular strategies that companies in the UK could use to implement mass customisation. It provides the parameter on how these should be implemented.

Accordingly, this thesis describes one of the multiple connections that industrial production has with housing and sustainability, where mass customisation is presented as a potential solution for increasing the production of zero energy houses, and in turn, reduce the carbon emissions of the housing sector.

In the first chapter, the thesis described the reasons for conducting the research and presented the research hypothesis, questions, aims and goals, in which, this thesis was written. The second chapter described the methodology and research methods used to develop the research. Chapter three redefines the ZEMCH term in relation to primary information extracted from an interview to Masa Noguchi, supported with literature review on the terms mass customisation and zero energy. ZEMCH was defined as a single concept rather than as a contraction of different terms. Chapter four described the housing contexts of Japan and the UK, identifying their differences similarities. Chapter five described the housing procurement processes of Japanese mass customisers and speculative housing developers in the UK. Chapters four and five were developed through a literature review, supported with diagrams and graphics developed by the Author. Chapter six described the production processes and capacity of house manufacturers in Japan and the UK using primary material collected in fieldwork. It demonstrated that the UK manufacturing sector has the capacity to produce variable outcomes needed for mass customisation. Chapter seven described the co-design, marketing, and selling processes of companies in Japan and the UK using primary material collected in fieldwork. It identified the strategies that Japanese house manufacturers are using as part of their mass customisation systems that are lacking in the UK. It also described the importance of informing customers about the benefits of energy-efficient features for the mass customisation of zero energy houses. The last chapter (chapter in question) briefs the thesis arguments and answers directly to the research questions.

This research concludes by identifying the strategies that can be implemented by house manufacturers in the UK. Further research is needed to identify the appropriate ways and mediums to apply the co-design, marketing and selling strategies that adequate to each companies' capacity and market focus. This requires marketing research developed from the perspective of each company.

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Appendices

Interviews

Masa Noguchi

An interview on a bus between Toyohashi and Misawa Homes (Osaka). I started showing him the documents I prepared for the mission to Japan. Then, we talked about the reasons why Kate Davis was not able to join the Mission.

Professor Dr Masa Noguchi
Dr Masa Noguchi is an Associate Professor in Environmental Design at the Faculty of Architecture, Building and Planning, University of Melbourne, Australia.

Trying to avoid the obvious reason that you are the main man organising this event, and that without you it could not be possible.
Which is the main motive that brings you here to the ZEMCH mission to Japan?
The reason behind it, are based on routine, if they do not see applicability. ***

Try to show that ZEMCH is marketable and profitable.

b) Dr Masa, you were borned in Japan and live your young years here; but you have also reside in Canada, Scotland and now in Australia.How would you define "home", and which will be the main differences between Japan and the other places? (H) Which are the main different between House and Home. I believe there is a big difference between dwelling, house and home.
**Because in Japan, they don't say 'home', they call it in Japanese language (ホーム
ホーム Hōmu). In my own perspective, housing is a proces; dwelling is just a definition; but Home is the way people live, so I think that's why I feel really comfortable using Home rather than Housing, or Living Unit, which is more like a product, commercialised product. Housing is the way Living Units are delivered.**
Home is just natural, is where family gets together, people come back, children grow; for me is like a nest. Home sound softer and warmer; housing and dwelling are more mechanised. That's why ZEMCH uses homes instead of housing. However, grammatically is better to say HOMEs; Houses is another thing.
'House' (家) is also very close to the product. There is a common idea of *'turning a house into a home',* I agree with this common sense as House is a little bit cold.

Another important thing to consider is the difference between the concept, depending on their context. For example, a house in Europe, once you buy it usually start gaining value, so people look an investment on buying a house. Here in Japan is different?
Japan houses depreciate, it is exactly like cars. …. [go to audio]
Masa explained some of the cultural barriers, between Japan and other countries. Even consider NRGStyle

c) When a dwelling is manufactured off-site or in a factory, it can be ensured that some of their construction aspects will be improved, such as: construction time, ensemble, their material quality can be tested, and even the costs can be reduced. However, which are the qualities that a dwelling could be considered to risk when being manufactured in this way? (MC)

… there is a reserve from some architects (artists), or in the general public, to utilise off-site processes, considering that when something is industrialised — and by this, mass-produced — lose its authenticity and ability to incorporate to a specific site or user. Why would you think this does not happen? (MC)

Talked about LeCorbusier, Walter Gropius, and the creativity of how to create. He compare prefabrication of the 20's like a 'dream'. Also talked about prefabrication of design.

~~There is a popular phrase, which says that "one size fits all". This phrase even became a guide for the industrial process of the 20th century. In this technical tour we have appreciate how this paradigm has been replaced for a mass-customised paradigm. Which have been the most significant changes that transform housing industry? At least from the Japanese point of view. (MC)~~

~~d) In the market, there is an obvious increasing desire for customised products (including homes), which do you think are the main reasons for this to happened?~~

After the second world war, Walter Gropius and Konrad Wachsmann — two of the most significant architects of the past century — intend to deliver mass-customised homes with their "Packaged house" project, or also Buckminster Fuller's "Dymaxion house". The reasons why they do not completely succeed are quite complicated; but, how would you compare their proposal with the triumph of mass-customised homes in Japan? (MC)
Walter Gropius was focused on academics, not a businessman. However, companies appear and bankrupt. He also talked about Sears Co and its natural bankrupt. Also about social lifestyles, changes and economies.
Comparison of social values, bike-nowaday value while bike-used to be a determination of being poor.

Quality is defined by users.
Choices are given by the suppliers.

Location, location, location.

Society is increasing their concern to reduce energy consumption and CO2 emissions. However, as zero-energy products tend to be more expensive, we usually opt for cheaper options. As it is seen, the mass-customisation process allow to reduce construction costs, and thus be able to include zero-energy features. But, who should

be the one that force zero-energy features in homes; the consumer, manufacturer, or external elements as government or social institutions? (ZE)
Policy, that's it. Builders do not make research, they just do contract; so, if they are not forced, they do not do it.

Cost-performance

~~The term "zero" stands for the absence of. Inevitably, in order to build or to maintain a house an energy source has to be used.~~
~~Why use the term "zero-energy" instead of low energy, passive house, zero-carbon, etc? (ZE)~~

~~… therefore, zero-energy should be seen as ambition or as a standard?~~

~~Zero energy homes allow the user to save, not only CO2 emissions, but also money in a long term. In this way, the energy features are seen as a plus, a commodity, or a quality of the house? (ZE)~~

When was the first time the term ZEMCH was used, and how it was conceived? (ZEMCH)
[e) when was the first time you heard the term ZEMCH, and which was your impression about it?]
Very simple. Starting point is Mass-Customisation, is all about production efficiency, and all about user choices. But, users choices alone, can not achieve what society is looking for *"green things',* using mass customisation does not work for providing *green* options. Specially because some definitions are not really clear. Low-Energy for example, if a house user turn off the light of a house, that could already be seen as low-energy. But then, if I say zero/carbon, carbon emissions are calculated by carbon power plants; therefore, it depends on local context. For example, a house located on a country where 100% of the energy comes from hydroelectric plants, the house is already zero carbon. But, if I am talking about energy, energy is energy, is the same everywhere, a KW is a KW. So zero energy is simple, zero energy need to be standard.
While zero-energy needs to be a standard, mass-customisation is a socially need. Thus, ZEMCH is a social, economic, environmental sustainability; not only environmental sustainability. All thing come together is ZEMCH

The ZEMCH term was together in 2010, I used to called it Zero Energy Mass Custom Home mission. I never called it ZEMCH. It was Hasim that used to have the homepage, he was the one that put ZEMCH conference, and then I started the Network. It is not really me [continue talking about the Network]

~~Dr Masa you are an engineer and an architect, but above all you are a professor.~~
~~f) How does ZEMCH relate to your practice?~~

~~g) Which could be the complications of applying this practice where you come from?~~

Ben Murphy

The questions are open, but I added some keywords in grey that can help you to guide your answers towards my interests. You can fill the answers in the email and simply reply to me.

In which operation
would you say is where Robertson (Timber Engineering) mainly gets it profit?

~~Land development~~
~~/ speculation~~

~~Manufacturing~~
~~products (added value to materials)~~

Managing the
construction

Robertson has manufacturing plants (factories), but you have a flexible construction process and you are not dependant to the materials produced in your factories. How/ when do you prefer to use the products you manufacture? (timber frames, etc)
Robertson only manufactures timber wall panel which are used on all residential project as a company standard. In other word we don't use an outside timber wall panel manufacture but for roof trusses we Sub-Contract that out. We only use a different frame when the client requires that we build in a different method (concrete, CLT, Steel, etc.) For commercial construction project we rarely use the inhouse timber engineering due to the construction methods and regulations required. However when we are able to use our inhouse product we will use them every time.

Why is it important
for your company to use off-site construction/ prefabrication?

~~Workers' skills~~

~~Quality / Energy~~
~~Efficiency~~

Cost / Time
/ Productivity

~~A shift of~~
~~target in the market~~

Graham Shawcross

Development Computer Aided Design Systems Housing Research and Development Component Development Specialties: Architectural Computer Aided Design Visual Research Order, Rhythm and Pattern in Architectural Design

I am an architect with many years of experience in Housing R+D, Computer Aided Design Programming and latterly the design of secondary and further education establishments.

I have recently started a PhD in Architecture at Edinburgh University and am interested in formal order, rhythm and pattern in architectural design.

Questions:
Tell you tell me a little bit about yourself, particularly about your professional experience with housing in the UK.

I qualified [as an architect] in 68' and my thesis was in suburban housing. Then, professor of planning wrote to the Ministry of housing and said you should interview this guy… At that point, the Ministry of housing was designated in charge of all the new Towns like 'Livingstone', …

… at that point prefabrication as housing, shelter; the 'prefabs' were considered a thing of the past?

No, no. The unity I went to work was called the 'R&D' group and they developed two sets of prefabricated houses before I arrived. One of them was called '12 M'; which was 12 modules…, which was a large prefabricated concrete scheme. And the other one was '5 M' which was made of panels that 2 men could assemble. And they build a trial for this in Sheffield.

The things you had are these man handle units and prefabricated staircase. They did this activity samplings, where somebody walks around the site every hour ticking each person and what were they doing. And then you can walk backwards how long they spend on each task, and how often people are waiting, not doing anything. So you can work-out the productivity on site.

And the M5 had this prefabricated staircase, which was craned, everything else manhandled. And it took them an enormous amount of man-hours to fit this prefabricated staircase. And it was all because it has details where you have to scribed bits of the staircase in the wall. It was taking 30 man-hours to fit the staircase. And, my first job was to work with the R&D to design a staircase that could be put quickly.

We designed one that was no touching the walls…, and this was taking 13 man-hours to put it in …

So, that is how we worked, we did man-hours studies and figure out which tasks could be improved in the next scheme.

So it was a lot about productivity?... But, you mentioned there was also a sense of flexibility as they were designed as modules. What was the interest [of the department] on these modules?

It usually worked the other way around. There was sociological research … they will survey the people living around finding what proportion of the houses were needed; how many 6 person houses, how many 5 person houses, how many 4 person, how many 2 person. How many single storey [houses] was needed as well. So they did social surveys to see what the mix was. So the idea was to make a mix that was already pre-defined; … and you have to integrate them on the site.

But these houses were not given directly to the people surveyed.

No. … It was just a sample to see which are the houses needed. … We make the mix of houses and put them together in a way that were in some way attractive, and efficient.

When they did the man-hour study they found that when you did 50 of the same houses, you still getting better [in time]. But as soon as you changed type, the man-hours get up again. … Overall, you were getting down … But, every time you change type, or a handle even, [man-hours increase].

(You think it would be the same to build a right-handed handle than a left-handed…)

We were really successful with the foundations and really successful with the shell. For the foundations, I designed prefabricated foundations which were beams. (... and all installations were in one place coming down from the first floor to the ground floor…). The funds were fantastically efficient, they were craned in … And the Shell went up in a day, it was prefabricated timber panels with a finish on and plasterboard on the inside, and internal partitions.

So, you put the ground floor, the foundation, put the walls, then the second floor, and then the roof on. Everyone could do the shell in a day, it was not really hard, it was just **assembling.** The panels were connected with screw bolts. Screw to the timber.

So, besides the plan, the houses had other variables?

Left and right hand; and type.

Materials were not different?

All the panels were very similar. They were plywood with a spray finish.

The panels, as prefabricated objects, were those better in insulation?

They probably did. They were not incredibly high, but they were stuck with fibreglass. [time] Efficiency was more important…

These were permanent houses?

Yes. Permanent. … The whole series of prefabricated houses (the steel houses, Swedish timber …, Cornish units), there were about 20 different programmes, and there are still some around. They were not designed for a limited lifespan, that is probably a mistake …

…

They made surveys about these houses. But everybody is happy with a new house really. So, we always got good reports.

Now the word 'Prefab' has a bad reputation. Why do you think the Prefab reputation fall in the following years? How do events like Ronan Point affect that?

I was working in the Ministry of housing, and the day that Ronan Point happened everyone knows this was the end. It was absolutely immediate. This picture. So, this was really a turning point.

So, what happened to prefabrication after that?

(Prefabrication continue, it was about efficiency. The surveys discovered that the most efficient builder was a traditional constructor in Wales that have been doing the same house all his life. In hours the problem was the installations, etc.) The idea of the program was to improve …

We had 120 different types of doors, just because we were not careful of how to make the details (the little designs); which was very inefficient … (It was about who does it, what is needed and how to coordinate them) (18:36) ...

It was all about productivity. That was because there was a shelter need?

It was all about taking the man-hours down and have a scheme that was attractive. It was done properly. It was done with creativity in mind. You have to produce something that was acceptable in quality; more than acceptable. We were the ministry of housing, we were the example to show people how to do things.

Who was pushing the quality up? Were there any standards?

There was a space standard. … There was a functional restraint. And there was a density-cost … (Quality, in reality, was the same, but you have to respect the limits, financial limits mainly). (Park and Morris standard-minimum standards). …

[Talking about the images in the book]

(These were very efficient because they were all the same)

The project you were involved was more interesting because it involved variability.

Yes. We needed to cope with a special need. When there is a lot of need, any house will satisfy [referring to the Prefabs]. But, in the late 60s', we had to be more sophisticated than that. … You have to get wheelchair houses. We were building for real needs. [This affected not only the entrance with the inclusion of a ramp]. All internal aspects need to be different, you need to have wider doors; so, the plan becomes different.

But is a new house or just variables of the same?

It is a new house. It is a material consideration. Changing a door from 900 mm to 1000 mm breaks everything. Furniture doesn't fit, you really have to start designing a different house. …

So how were you dealing with all these modifications?

Dimensional coordination. Everything needed to be exteriorly modular to 300 mm and internal modular 100 mm. Windows needed to be 300 mm modules.

In one case my boss asked me to modify a window 100 mm, and it took me a whole week (because it was out of the system).

The restraint was that everything needed to be dimensional coordinated. The idea was that you have fewer doors [components] and eventually manufacturers would do it cheaper because they were all the same. Which is not how it works out.

You still see in drawings that doors are 9'x12', because that is how works in brickwork; so 9'x12' is a brick dimension. … Doors manufacturers that know what their real market is they build doors 9'x12', which is what all replacement doors are. These rules apply for the whole market.

So, you got doors designed especially for you?

So, door manufacturers decided they have to build any size of doors and set their factories to do anything. They just had gigs that they adjust. Thus, dimensional coordination became something of the past.

[CAD] Dimensional coordination worked really well when it came to computer-aided design …, but in production, it didn't make much sense. (34:..)
(44:20) [We used CAD] only to produced new house types being sure we comply with the quality standards (Park and Morris) and meet the building criteria and be sure it would work in construction.
Construction details were assumed, and then we had a details book that shows you how things need to be done. And then were specification books that tell you how to do it. But, the contractor could decide which one to use, in terms of materials [and hence, the detail]. We had 7 manufacturers that made all the windows and they sent the details. The nomination was not allowed, which was really good but require redundancy in everything. We need to have 3 of everything. We need at least 3 suppliers in everything.
Consequently, the look was all the same, the plans were all different. (46:30)

(34:30) In terms of quality, for example, we were painting 3 times each wall. So we had a painter painting 3 times each wall to paint everything white, and it's nuts because the person who moves in would like to redecorate anyway. So, you waste all this time painting the walls, so we were building to a standard that was higher than necessary.

Is this a problem in prefabrication?

Yes, redundancy is a big issue. If you design houses that can move the partitions you might have a more expensive partition that never gets moved. If it was a normal partition you could probably knock it down and build a new one. You need redundancy in everything, but then somebody comes and ask you to take the redundancy out and make it cheaper. I think, not finishing things is a smart move. (36:04)

Variety comes from what people do, from the decisions they make. Customisation should come from individual choices. And then it's real, anything else is artificial variety, always looks very unsatisfactory. (43:15)

(Graham talking about this idea)

Paper: 'Plain and provision' - look for it.

Samuel Gonçalves

Samuel Gonçalves was born in 1988 (Arouca, Portugal). He graduated in Architecture from Faculdade de Arquitetura da Universidade do Porto in 2012 and spent one year studying at the Pontificia Universidad Católica de Chile under an interchange academic program. He worked for one year with the Chilean studio ELEMENTAL, led by Alejandro Aravena. In 2015 he created his own practice, SUMMARY, and he was a finalist for the Portuguese National Prize of Creative Industries. In 2016, he was invited to join the main exhibition of La Biennale di Venezia - 15th International Architecture Exhibition "Reporting From the Front", representing his practice, being the youngest studio in the whole event.

Why do you think prefabrication is not selling as much? Considering that it has some advantages.

For us, as an architectural practice, is difficult to sell a prefabricated project; because it is dependant on the prefabrication system. So, people [customers] want to know the price from the beginning.
That's not an advantage?
No, I think people like to be tricked, somehow. They like to believe that the house would be cheaper that it would actually be at the end. So when you tell them the [accurate] final price they feel is too expensive. There will always be a contractor saying, "I can do that cheaper", but in reality it would be more expensive at the end.

But, when they [the customers] order a prefabricated house, they want to know the exact price, because they will create a dependency with a supplier. If they opt for a traditional process, they are not dependant on a single supplier [contractor]. They can negotiate [or change]. (They need to be certain about the price before committing to the full project). … But, for us to give them the full price I have to develop the full project first, including quoting the cladding, windows, etc… and to do this project, someone has to pay me, but the clients will not pay if they do not know they will pick ur offer or not. (They want to compare).

Prefabrication is a problem of procedure [order], not a technical problem.

(Traditional procurement allows them to speculate with their money, while in prefabrication they commit to something. Traditional construction works by price for sqm, while prefabrication for project). This is always a barrier. Who pays for the project? Nobody.

Traditional contractors/ architect there is a constant negotiation.

In that sense, prefabrication has a disadvantage against self-built, but what about mass housing where there is also a fixed price?

{mass housebuilders have financial capacity to invest first, that is why this business model depends on having stakeholders}

So, what are the advantages of prefabrication?

The advantage is not the price, is the time. So, investors [contractors] they understand the advantages of time. But the final client, it is a house, a life-project … saving time is not important. These guys don't buy it.

And as an architect, which is the interest or advantage?

There is no advantage, it is a dream of getting an advantage. A dream of getting simpler projects, by having optimised [design] procedures.But in practice, we haven't got that. The time we spent in our projects is the same than traditional. … We can't produce the same, we always need to re-process the system. (13:17)

Your system hasn't changed in shape, what are you changing?

Shape is always the same. But, within this shape we have different ways to work with it. (We need to adapt to the context). So the illusion of getting things faster because you are working with modularity maybe is not that true. The good part is that if you get to solutions that you are building faster you provide advantages.

So how are you dealing with the balance between repetition (for faster production) but achieving variety to adapt to the context or clients needs?

[Variety] is one of the forces that pushes back prefabrication. Of course is not as flexible as traditional buildings, virtually. I think you need to direct your creativity [as an architect], not only in the design process, but to convince the client that predetermined projects also match their needs. … if it was me, I would repeat always the same project, but that would never happen, it's impossible. When people think about architecture, they think about customisation. Architecture is an activity of customisation. (20:02)

But, you designed the system to possess certain flexibility?

No, I was not aware of this. I thought that with the module, we were capable of changing the cladding, amount of modules [size], etc., and with this solve any problem; but it was not true. Because people always want to change something else: dimensions, shape. …

We started creating this project for houses, but single houses was not the best market. Now we are building collective housing and mixed use projects, which are bigger investments, but not single housing.

It is for investors, for clients interested in selling or renting. For them, repetition is interesting. Reduction in construction time, help them to get the money back in a shorter time.

For the investors is about timing. For the final client is all about customisation; the color that they want, the kitchen of their dreams.

How often do you encounter that clients want to customise in terms of quality, such as resistance or thermal comfort?

Usually clients just want their projects to comply with the minimum. All the clients, including the final clients. They do not see value on the technical advantages that prefabrication can provide (as less thermal bridge with continuous insulation).

Do you think this is a matter of misunderstanding?

(25:50) The technical arguments provided by the prefabricators, could be promised by any traditional constructor. So, it is not a commercial advantage, because is played by all.

Quality is very difficult to sell.

How do you compare to car marketing, where the quality is compared with specific criteria as horsepower?

It is curious because the industrialisation of houses started at the same time as the automobile industrial production. But, you can see how they evolved so different; one evolved and one got stuck. Why they followed very different paths, if they aim for similar goals.

Can you tell us about the Gomos system? Its origin, evolution, present, future, ambitions and desires.

We started developing 2013, the first prototype was build 2015. Then, a bigger project was finished in 2017. Now we are building 11 houses very recently.

We just get design fees. In some particular projects, where the contractor gets the project they pay us some design fees. The client pays to the contractor and to us, both ways.

We don't have a patent. The protection that we have is that the process of the system is complicated, only we know it.

Our process is messy in commercial sense and procedure, as any creative industry, even though should be cleaner because is prefabricated.

How do you search for technology? New or old?

It is not about new ways of doing things, is about the only way to do things. I am not obsessed with technology. (49:15) <u>I prefer to make things happen</u> and the easiest way is to work with the resources available. Otherwise, you'll never get the investment. But, if you prove to use existing systems work, investors or manufacturers could accept to modifications or innovations, never from the beginning.

People [in Europe] do not care about technology in the housing context. They care about technology in the cars. (52:08) [Prefabrication] in a european context is not an advantage, it is becoming a need. Everyday we have less people available to work in construction, so traditional building will get expensive. Thus, prefabrication would get cheaper, not because of economies of scale, but because the inflation of traditional construction.

(55:00) People are getting more dependent on immediacy. We are getting used to this facility. Construction is not following this global demand for affordable repetivity; particularly in post-crisis economies.

Mike Cruickshank

Sales Director at Scotframe Timber Engineering

What are the options of sustainable productions you provide?

Scotframe has developed a production process that allows variable thermal levels on their panels, which can vary from 0.09 to 0.23 in U-value. Passive House guidelines suggest a range between 0.10 to 0.15. Scotframe construction kit does not include mechanical systems or renewables.

Injection insulation (34:30)
Made from 86% recyclable vegetable oil
Floor or wall timber frame
Injected in a press

How many opt for premium:
60% of customers for the closed and its increasing.
Some customers understand the long-term value /
'from my point of view, is the cost benefit of putting insulation off-site, meaning it is more expensive to achieve the same insulation levels on-site'

Why don't you include solar panels in your houses?

Renewables (18:20)
'Most clients don't really want renewables' … They don't also like the fact that they need to maintain them… thermal heat pumps… its far too complicated for them… renewables are imported, so doesn't help the economy…

Full tables and matrix of data

Comparison of cities

Japan			UK		
City	*Population (Million)*	*Density (p p/sq km)*	*City*	*Population (Million)*	*Density (p p/sq km)*
Greater Tokyo	38.14	6,150	Greater London	8.83	4,500
Greater Osaka	19.34	5,200	West Midlands (B'ham)	2.90	3,650
Nagoya	11.00	7,080	Greater Manchester	2.80	4,700
Sapporo	2.30	1,700	West Yorkshire	2.31	1,130

Calculation of Scotframe house prices per square meters

	area	5 closed	1 open	5 price per sqm	1 price per sqm
type 1	109.44	£38,565	£27,310	£352	£250
type 2	175.07	£60,375	£45,335	£345	£259
type 3	206.28	£83,535	£59,800	£405	£290
type 4	171.9	£56,740	£40,370	£330	£235
Average		£59,804	£43,204	£358	£258

Calculation of house prices of the speculative sector in the UK

Barratt				
model	location	price	size (sqm)	price per sqm
MCLaren 77	Edinburgh	£203,995	93	£2,193
Inglis 26	Edinburgh	£148,995	62.09	£2,400

Fleming I 255	Greater London	£574,995	124.236	£4,628
Aylesbury	Lancaster	£181,995	67.68	£2,689
Robertson homes				
PLot 97	Auchterarder	£194,000	85	£2,282
Sienna	Mid Calder	£427,995	187.45	£2,283
Calico	Mid Calder	£245,000	118.38	£2,070
Willow Grand	Mid Calder	£414,995	213.6	£1,943
Persimmon				
Woodlea Park	Dunfermline	£142,000	58.374	£2,433
The balerno	Dunfermline	£229,000	132.902	£1,723
The Lawrence 513	Greater London	£555,000	90.42	£6,138
Taylor Wimpey				
The Geddes	Midlothian	£285,000	91.392	£3,118
The Sinclair	London	£1,320,000	224.46	£5,881
The Balfour	North Lanarkshire	£180,000	77.76	£2,315

Matrix of information of companies in the UK

	UNITED KINGDOM	**Housebuilders / Housing developers**			**Contractor**	**Contractor**	**Manufacturer**
		Barratt	**Persimmon plc**	**Taylor Wimpey**	**Robertson G**	**Facit Homes**	**Scotframe**
	Homes completed in 2015	16,647	16,043	13,341	200	< 50	1,500
	Average selling price (Unit Cost)	£275,200	£213,321	£287,000	£300,000	*£500,000*	*£50,000**
Finance (£M)	**Turnover / Revenue**	£4,650	£3,422	£3,965	£565	< £2	£30
	Operating profits	£799	£966	£841	£24		£2
	Net Income	£616	£787				
	Net Cash	£724	£1,302	£511	£66		£0.2

	Return on Average Capital Employed	30%	51%	34%			
Balance Sheet	***Land***	*£2,895*		*£2,684*			
	Land Creditors	*£1,064*		*£639*			
	Work in Progress	*£1,509*		*£1,391*			
Land	**TOTAL Number of plots (land)**	80,752	98,445	192,094	-		-
	Acres held (2017)	11,737	16,100	-	-		-
	Number of Plots in 'short-term landbank'	70,523	54,300	76,000	-		-
	Plots anticipated from 'strategic land holdings'	71,600	100,000	107,000	-		-
	Number of land approvals (per year)	18,497	17,301	-	-		-
	Strategic land (plots)	70,000	218,750	103,800	-		-
	Completions from strategic land	25%	51%	53%	-		-
	Conversions to owned land bank (plots)	6,757	8,296	7,863	-		-
	Land owned (plots)	58,965	52,600	83,455	-		-
	Land controlled (plots)	16,078	21,400	108,639	-		-
	Land bank years (average)	4	6	6	-		-
	Land cash spend (annually)	£ 1 bn	£ 602 M	-	-		-
	Gross margin	20% min	31%	28%			-
	Land Return on Capital Employed (ROCE)	25% min	51%	34%			-

	Supply agreements	199					-
	Suppliers	160	>1000				-
	Unsold stock	1%					-
	Profit from operations	£800	£786				
	Inflow from operations	£388	£997				
	Working Capital	*£80*					
	WIP	*£120*	*£724*	*£1,391*			
	Land	*£25*		*£2,684*			
Investment	**Investing: Purchase of property, plant and equipment (£M)**	£4.0	£18	-	-		£5.2
	Dividends (£M)	£321	£416	£80	-		(£5,000)
	Loan repayments	£106		£812			
	Total DEPRECIATION:	-	-	-	-		£3.00
	Improvements to property	-	-	-	-		£0.48
	- Plant and Machinery	-	-	-	-		£1.95
	Motor vehicles	-	-	-		£0.06	-
	- Fixtures and fittings	-	-	-		£0.51	-

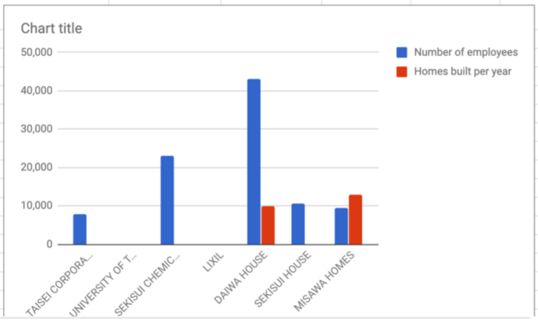
Matrix of data of housebuilders in Japan and the UK

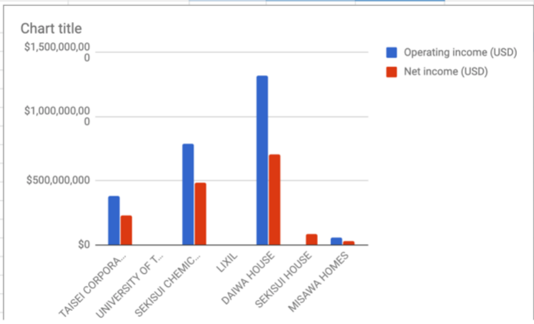
	Company	Revenue (Million GBP)	Output* (houses per year)	Employees* (housing sector)	Number of factories	Annual units per employee	Supply Chain Strategy	Manufacturing Layout	Structural material	Construction system	Off-site/ On-site	Foundation	Price Range (sqm)	Customer involvement: Bespoke Tailored	Standardisation	Model Catalogue	Configuration	Personalisation	Sustainable options for the customers: Insulation	Glazing	PV / PVT	Mechanical Vent	Heating/ Cooling	Monitoring systems	Batt /CarPlugs	Customer Approach: Show Villages / Homes	Customer Centres	Word-of-mouth sales	Repeat business	Catalogue	Customer Service: Warranty (years)	Maintenance	Upgrade	Recustomisation
JPN	**Sekisui House [M]**	£14,060	13,612	15,302	5	1.12	Make to order	Flow-line like, group-like	Steel / Wooden	Volumetric	60/40 %	1960	£2,250-3,500	X	X	X	X	X	X	X	X	X	X	X	X	X/X	X	X	X	X	>20	X	-	-
JPN	**Daiwa House [M]**	£24,371	9,286	4,644	10	0.50	Make to order	Flow-line like, group-like	Steel / Wooden	2D pre assembled frames / Panels	60/40 %	1955	£2,050 -3,256	-	X	X	X	X	X	X	X	X	X	X	NC	X/X	X	X	X	X	>20	X	-	-
JPN	**Sekisui Heim [M]**	£7,388	13,620	10,447	8	0.77	Assemble to order	Assembly line	Steel / Wooden	Modular Volumetric	80/20 %	1947	£2,250-3,500	-	-	X	X	X	X	X	X	X	X	X	NC	X/X	X	X	X	X	>20	X	X	X
JPN	**Toyota Home [M]**	£890	5,400	3,402	3	0.63	Assemble to order	Flow-line like, line-like	Steel	Volumetric / 3D steel frames	85/15 %	1975	£1,840-3,256	-	-	X	X	X	X	X	X	X	X	X	X	X/X	X	X	X	X	LT	60	-	-
UK	**Facit Homes [PC]**	< £2	<50	< 30	-	-	Assemble to order	Workbench-like	Timber Cassette	On-site CNC kit parts	0/100 %	2007	£2,100	X	-	-	-	-	-	-	-	-	-	-	-	-	-		X	-	NC	NC	-	-
UK	**Scotframe [M]**	£30	1,500	200	2	0.13	Assemble to order	Flow line like, Chain-like line	Timber Frame	Panel	>50 / - %	1987	£260-360 (+ £1,350)*/**	-	X	X	X	-	X	X	-	-	-	-	-	-	-			X	NC	NC	-	-
UK	**Stewart Milne [M]**	£210	1,000	900	2	0.90	Assemble to order	Flow-like line	Timber Frame	Panel	variable	1975	-					X			-	-	-	-	-	/ X							-	-
UK	**Robertson Homes [RE]/ Timber Engineering [M]**	£565	-	1,943 / > 100	2	-	Ship to stock / Assemble to order	Flow line like, Chain-like line	Timber frame	On-site (traditional) / Panel	variable	1966	£1,950-2,300*	-	-	-	-	X	-	-	-	-	-	-	-	/ X	-	-	-	-	10	2	-	-
UK	**Barratt Homes [RE]**	£4,650	17,395	6,214	0	0.36	*Ship to stock*	-	-	On-site (traditional)		1953	£2,200-4,600*	-	-	-	-	X	-	-	-	-	-	-	-	/ X	-	-	-	-	10	2	-	-
UK	**Persimmon [RE]**	£3,422	16,043	4,535	0	0.28	*Ship to stock*	-	-	On-site (traditional)		1972	£1,200 -6,100*	-	-	-	-	X	-	-	-	-	-	-	-	/ X	-	-	-	-	10	2	-	-
UK	**Taylor Wimpey [RE]**	£3,965	13,341	5,183	0	0.39	*Ship to stock*	-	-	On-site (traditional)		2007	£2,300-5,900*	-	-	-	-	X	-	-	-	-	-	-	-	/ X	-	-	-	-	10	2	-	-
UK	**Laing O'Rourke [C]**	£4,000	-	17,000	1	-	-	-	Concrete / *Steel*	*Modular*	-	1978	-																					
UK	**Caledonian Modular [C]**	£12	-	300	7	-	Assemble to order	Group-like, Flow-like	Steel	Modular / Steel frame	>70 / -	1964	-																					
UK	**Portakabin Group [M] (Yorkon)**	£224	-	1,750	1	-	Assemble to order	Workshop-like, Flow line	Steel	Modular	>70 / -	1961/1981	-																					
GER	**Huf Haus [M]**	£73	100	280	1	2.80	Assemble to order	Flow-line like, Chain-like	Wooden	Wood frame	>60 / -	1912	from £ 1,500																					
GER	**KAMPA Haus [M]**	£167	1,086	800	1	0.74	Assemble to order	-	Wooden	Panel / Frame	>60 / -	1900	from £ 530																					

Initial information matrices and fieldwork tables.

Exmples of the sections of the information matrices developed in intial stages of the research and during fieldwork.

est.	Name	Area served	Revenue (USD)	Operating inco me (USD)	Net income (USD)	Total Assets (USD)	Number of employees	Industry	Homes built per year	Homes built	Zero/Low Energy homes built	Patents	Comentaries
1873	TAISEI CORPORATION	worldwide*	$17,558,416,000	$378,586,000	$231,195,000	$3,650,187,000	7,945	Construction					Building Construction, Civi
1877	UNIVERSITY OF TOKYO	Japan	-	-	-	-	-	Research	-	1			
1947	SEKISUI CHEMICAL CO			$784,841,801	$484,966,784		23,010	Plastics, Urban, **Housing**					company that provides n with PV
1949	LIXIL												
1955	DAIWA HOUSE	worldwide*	$21,351,000	$1,322,992,251	$705,042,000	$15,184,408,240	43,000	residential, commercial and institutional buildings	9,894	1,589,000	13,423		largest housing compar
1960	SEKISUI HOUSE	Japan, Australia, China, Russia, US			$82,565,606	$17,656,369,052	10,499	Real State		2,240,000	15,000	840	company that build more world
2003	MISAWA HOMES		$91,511,800	$53,327,747	$30,216,615	$2,060,223,750	9,400	housing construction	12,800				shares with MISAWA



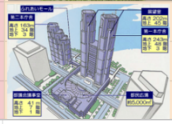


Summary of fieldtrip to Japan

Value		Evaluation grade
U-Value (general)	0	U-Value > 1.00
walls, roof, floor	1	U-Value > 0.30
	2	U-Value > 0.12
	3	U-Value < 0.12
U-Value (windows)	0	U-Value > 1.30
	1	U-Value > 1.10
	2	U-Value > 0.80
	3	U-Value < 0.80
space heating demand	0	>25 kWh m2
	1	> 20 kWh m2
	2	> 15 kWh m2
	3	< 15 kWh m2
Primary Energy Demand	0	> 180 kWh m2
	1	>150 kWh m2
	2	>120 kWh m2
	3	< 120 kWh m2
Airtightness	0	< 100 Pascals pressure
	1	< 75 Pascals pressure
	2	> 50 Pascals pressure
	3	< 50 Pascals pressure
Thermal comfort	X	in Celcius
Orientation	0	not considered
(North hemisphere)	1	South (+- 30°)
	2	South (+- 30°) + main windows
	3	all + west/east small widows
Cross ventilation	0	not considered
	1	considered
	2	in diferent heights
Compact shape	0	not compact
	1	compact
	2	compact semi detached
	3	compact in row

Company				Taisei Corp	Tokyo University	Sekisui House	Sekisui Chemical Co	Misawa Homes	Daiwa House	LIXIL Corp	Specifications
Project				ZEB	Smart house,						
designed by				Taisei Corp (First-class registred architect office)							
Location				344-1, Nasecho, Yokohama-shi, Kanagawa, Japan							
Building type				Office prototype	housing prototype	Hosuing	Housing	Housing	Housing	Housing Components	
Building total floor area (m2)				1,277.32							
Energy Consumed [kWh/(m2a)]				463							
Energy produced [kWh/(m2a)]				493							
Total Energy [kWh/(m2a)]				-30							
ZE	Materials		Wall U-Value								
			Roof U-Value								
			Floor U-value								
			Windows U-Value								
		Subtotal									
	Passive design		space heating demand								
			Primary energy demand								
			Airtightness								
		*	Thermal comfort	20-27							Celsius degrees
			Orientation	South							
			Cross Ventilation	3 (cooling tower)							
			Compact shape	3							
			Season adaptation	3							No shading summer
			habitants adaptation	3							
		*	Type of certification	LEED 2009 Platinium, CASBEE 2010, BELS 5-star							Passive haus LEED
		**	Energy simulation tool	T-ZEB simulator (own)							
		**	Passive lighting	T-light tube							
		Subtotal									
	HVAC		Energy use								
		*	Heating system								
			(Boiler) efficiency								
			MHVR								75%
			AC	Variable air volume control							
			Installation zones together								bathroom / kitchen
		Subtotal									
	Renewables		PV standard capacity								
			PVT inclusion								capacity
			Solar Water Heating SWH								
			Water renewable system	central system							
			Community energy system								
		subtotal									
	Monitoring system		Energy use	3							
			Energy generated	3							
			Water	1							
		Subtotal									
	Subtotal										
		*	customisation interface type	technical catalog							catalog, digital interface, showroom
			virtual rendering	3							
			level of customisation	2							
			customisation stages								0 - no customisation 1 - material
MC	design		customisation options								1 - material 2 - material + form (or any 2 combination) 3 - material + form + function
			simplicity	3							
		*	show room	yes							
			personalization								color, decorations
			Use of BIM	yes + 3D model							
			patents								
		Subtotal									
	Modularity		modules p/unit								
			module interchangeability								
			wall type								included in module or panelised
		*	proportion/scale used								
		*	modular aspect								
		Subtotal									
	off site / prefabrication		% factory produced								
			% factory assembled								
		*	foundations								
		*	delivery process								
			wall production								
		subtotal									
	Process		time per unit								
			workers per unit								
			waste produced								
			% of workers in the company								workers vs management
			% of robotic manufacture								
		*	plans made								
		*	Energy calculations								
		Subtotal									
	Subtotal										
HOME	Value		price per unit								
			price per m2								
			house average lifetime								
			demand								
			design awards								prices, recognitions
			other awards	2014 Environment Minister's award for global warming prevention							
		Subtotal									
	Post service		maintenance								0 - there is no 1 - guarantee 2 - guarantee + maintenance 3 - full life maintenance
			maintenance cost (user)								
			upgrade	yes							
			loyal customers								
			sell/buy								
		Subtotal									
	urban		public transportation connections								0 - just detached houses 1 - detached urban developments 2 - high density developments 3 - high density communities
			planning developments								
			density								
		*	average unit size								
			community development								
		Subtotal									
	post-modification		promoted by company								raw unit
			indoors								
			expansions/ reductions								
		Subtotal									
	Subtotal										
TOTAL											
*	No comparative criteria										
**	No comparative criteria + Corporation creation										

Initial table to be filled by hand in fieldtrip in Japan, including evaluation criteria.

ZEMCH	MISSION TO JAPAN 2016		2016.05.23	Yokohama + Tokyo		
Time	**Place**	**Activity**	**Adress**	**Keywords**	**Observations**	**Photos**
8.00	8.30 Keikyu Ex Inn	departure	4-10-8 Takanawa, Minato-ku, **Shinagawa**, Tokyo 108-0074 Japan	Hotel	tel (03) 54233910	
9.00	4-10-8高輪、港区、東京都品川区〒108-0074日本					
10.00		technical tour	Tustuka, Yokohama	**Urban-style ZEB, Research Centre**building construction, civil engineering, real estate development	Supporting Modern Society and **Environmental Protection** Through Leading-Edge Technologies	
11.00	Taisei Corporation Technology Centre (Nasecho, Yokohama)		横浜			
12.00			Tel (090) 90267669	Area served: Worldwide, not in europe	Established in 1873	
13.00		transportation				
14.00						
15.00	University of Tokyo, Komaba Campus	Technical Tour	Meguru, Tokyo	**Smart house, Zero Energy building**	in cooperation with LIXIL Housing Corporation's Eyeful Home Company	
16.00		research house visit + seminar		Tokyo off the grid?, The Institute of Industrial Science of Tokyo University	COMMA HOUSE (Smart House) run from August 2011 until March of 2016	
17.00	東京大学駒場キャンパス				the COMMA house (COMfort MAnagement) expect to have plans for a standard smart house by 2020.	
18.00	Tokyo Metropolitan Government Building	tourist?	Shinjuku, Tokyo			
19.00			新宿、東京			
20.00	Keikyu Ex Inn	back to hotel	4-10-8 Takanawa, Minato-ku, Tokyo 108-0074 Japan	Hotel	tel (03) 54233910	

ZEMCH	MISSION TO JAPAN 2016		2016.05.24	Koga + Toyohashi	HAPPY BIRTHDAY!	お誕生日おめでとうございます
Time	**Place**	**Activity**	**Adress**	**Keywords**	**Observations**	**Photos**
8.00	8.45 Keikyu Ex Inn	departure	4-10-8 Takanawa, Minato-ku, **Shinagawa**, Tokyo 108-0074 Japan	Hotel	tel (03) 54233910	
9.00				ホテル		
10.00		Factory & Exhibition visit:	Kakegawa, Shizuoka	one of Japan's largest homebuilders, superior standards, home/house, Zero Energy House	It is important to understand how the company has turn the customer desieres and sustainable features into quality standards.	
11.00	Sekisui House, ltd. Kanto Plant	- Steel frame production line	Tel (0280) 921531			
12.00		- Recycling facility	http://www.sekisuihouse-global.com/#concept	Founded in 1960. Expanded to Australia, Rusia, China, and United States since 2008	in 2013 Launched the Green First Zero model	
13.00	SEKISUI HOUSE	-Zero Carbon Emission house	静岡県掛川市		they prduce a declaration of sustainability	
14.00					**Important to research the production process**	
15.00		trnsportation				
16.00						
17.00						
18.00	Loisir Hotel Toyohashi	arrival check in	Toyohashi, Aichi		Check the possibility to find a cheaper place nearby	
19.00	ロワジールホテル豊橋		豊橋市、愛知県			
20.00						

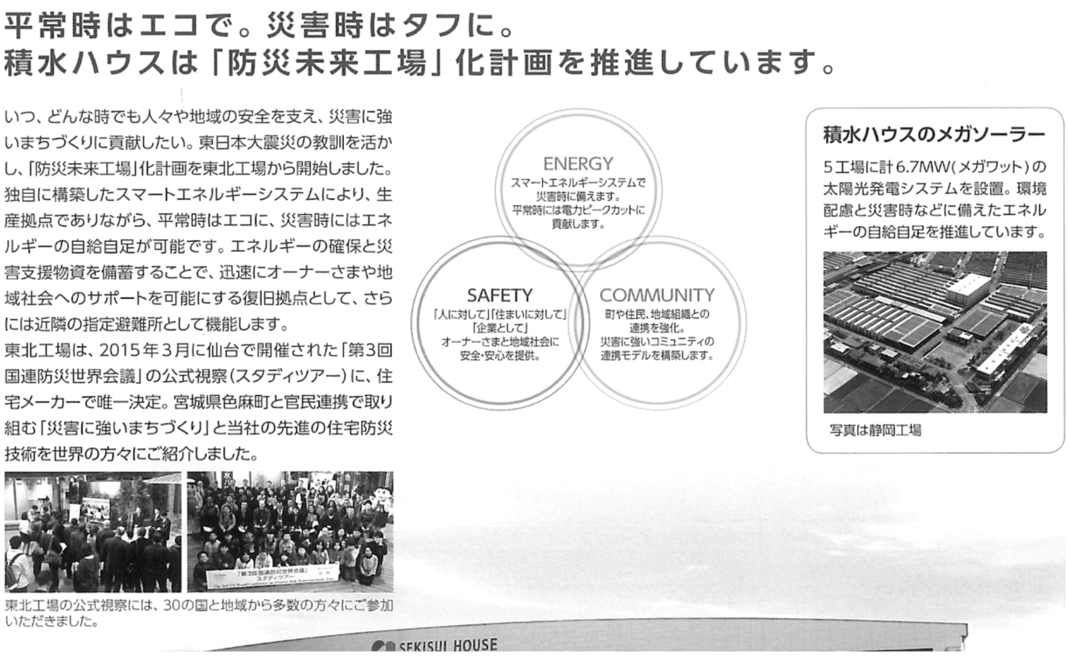
ZEMCH	MISSION TO JAPAN 2016		2016.05.26	Toyohashi + Osaka	Meet Atsuko	
Time	**Place**	**Activity**	**Adress**	**Keywords**	**Observations**	**Photos**
8.00	8.40 Hotel Nikko Osaka		Chuo, Osaka	tel (06) 62441111	Check the possibility to find a cheaper place nearby	
9.00			中央区、大阪			
10.00		Factory & Exhibition visit:	Sakyo, Nara	Safety and comfort, Environmental technology, robotics, **Density, not only detached homes**	This company is highly interested in producing "peace of mind" homes. And involve people in sustainable and community programmes	
11.00	Daiwa House Industry Co., Ltd	Daiwa Living 大和ハウスグループ Daiwa Living COMPANIES	Tel (0742) 702111			
12.00			http://www.daiwahouse.com/English/	founded in 1955		
13.00			左京、奈良			
14.00		Factory & Exhibition visit:	Kizugawa, Kyoto	Universal design, enviromental considerations, structural design	After visiting the factories it is interesting to see how they sell the products	
15.00	Sekisui House, ltd.,	SEKISUI HOUSE				
16.00			https://www.misawa.co.jp/en/info/group.html			
17.00	17.30 Hotel Nikko Osaka		Chuo, Osaka	tel (06) 62441111	Check the possibility to find a cheaper place nearby	
18.00			中央区、大阪			
19.00	Atsukini!					
20.00	敦子					

Planned schedule for fieldtrip to Japan

Translations

Extracts of translations of documents in Japanese via software

To translate


平常時はエコで。災害時はタフに。
積水ハウスは「防災未来工場」化計画を推進しています。

いつ、どんな時でも人々や地域の安全を支え、災害に強いまちづくりに貢献したい。東日本大震災の教訓を活かし、「防災未来工場」化計画を東北工場から開始しました。独自に構築したスマートエネルギーシステムにより、生産拠点でありながら、平常時はエコに、災害時にはエネルギーの自給自足が可能です。エネルギーの確保と災害支援物資を備蓄することで、迅速にオーナーさまや地域社会へのサポートを可能にする復旧拠点として、さらには近隣の指定避難所として機能します。
東北工場は、2015年3月に仙台で開催された「第3回国連防災世界会議」の公式視察(スタディツアー)に、住宅メーカーで唯一決定。宮城県色麻町と官民連携で取り組む「災害に強いまちづくり」と当社の先進の住宅防災技術を世界の方々にご紹介しました。

東北工場の公式視察には、30の国と地域から多数の方々にご参加いただきました。

ENERGY
スマートエネルギーシステムで災害時に備えます。平常時には電力ピークカットに貢献します。

SAFETY
「人に対して」「住まいに対して」「企業として」オーナーさまと地域社会に安全・安心を提供。

COMMUNITY
町や住民、地域組織との連携を強化。災害に強いコミュニティの連携モデルを構築します。

積水ハウスのメガソーラー

5工場に計6.7MW(メガワット)の太陽光発電システムを設置。環境配慮と災害時などに備えたエネルギーの自給自足を推進しています。

写真は静岡工場

SEKISUI HOUSE

平常時はエコで。 災害時はタフに。

積水ハウスは|防災未来工場」 化

いつ、 どんな時でも人々や地域の安全を支え、 災害に強
いまちづくりに真献したい。 東日本大震災の教訓を活か

計画を推進しています。

積水ハウスのメガソーラー

し、 [防災未来工場]化計画を東北工場から開始しました
。 ENERGY 5工場に計 6.7MVWV(メガワット)の

独自に構築したスマートエネルギーシステムにより、 生　　　　。 が時に條えます
。　　　　　　太陽光発電システムを設置。 環境
産拠点でありながら、平常時はエコに、 災害時にはエネ　　　5　　　　　梶
ご災音時なとに個えたエネル
ルギーの自給自足が可能です。 エネルギーの確保と災 。 レンーーベS、 ング

害支援物資を備革することで、迅速にオーナーさまや地 /グ　　　NZ_

域社会へのサポートを可能にする復旧拠点として、さら // SAFETY NN COMMUNITY

には近隣の指定避難所として機能します。 1

東北工場は、2015年 3月に仙台で開催された「第3回　N RE / に拉いコミューティ0の

国連防災世界会議」 の公式視察(スタディツアー) に、住 ベベ、　　　ング

宅メーカーで唯一決定。 宮城県色麻町と官民連携で取り　　ペペューージグ

組む「災害に強いまちづくり] と当社の先進の住宅防災

技術を世界の方々にご紹介しました。

と 7　!　1
東北工場の公式視察には、 30の国と地域から多数の方々にご参加
いい大大寺きましだ。

。 。 錠合cFMIKIUI HOUSE

写真は静岡工場

It's eco-friendly at normal times. Be tough in the event of a disaster.

Sekisui House |Disaster Prevention Future Factory"The

at any time, at any time, to support the safety of people and communities, and to

I would like to make a genuine donation to the town of New Year's Day. Taking advantage of the lessons learned from the Great East Japan Earthquake

plan to promote.

Sekisui House Mega Solar

the DisasterPrevention Future Plant was launched from the Tohoku Plant. ENERGY 5Plant Total6.7MVWV (Megawatt)The

With our own smart energy system, we are able to create a living. Sometimes it's time to go. Installed a solar power generation system. The Environment

Although it is a production base, it is eco-friendly at normal times, and energy 5 energy 5 energy at the time of the disaster and the energy which was able to be done at the time of the disaster

It is possible to be self-sufficient. Securing energy and disaster in addition, the RenbeS, Ng

By providing damage relief supplies, the owners and the ground /NZ_

as a recovery base that enables support to the community in the region // SAFETY NN COMMUNITY

acts as a designated shelter in the neighborhood.

The Tohoku Plant was held in Sendai in March2015, and the 3rdN RE /Abduction 0of

Official visit to the United Nations World Conference on Disaster Prevention (StudyTour)

It is the only decision in the house manufacturer. In public-private partnership with Seima-cho, Miyagi PrefecturePepeuzig

disaster-resistant urban development and our advanced housing disaster prevention

We introduced technology to people all over the world.

and seven! One.

A large number of people from 30countries and regions participated in the official inspection of the Tohoku Plant.

It's a good daiji temple.

。 In addition, the LockcFMIKIUI HOUSE

The photograph is Shizuoka Factory.

資源循環
Reduction, Reuse, and Recycle of Natural Resources

工場と一体となって、施工現場のゼロエミッションに貢献する資源循環センター。

Resource circulation centers work hand-in-hand
with factories toward zero-emission of building waste.

いち早く新しい資源循環の取り組みを進め、各工場に資源循環センターを設置し、業界初の4部門（生産・新築施工・アフターメンテナンス・リフォーム）のゼロエミッションを達成しました。各工場で発生する27種類の建築廃材を、資源循環センターで最大80種類へ分別。3R（リデュース・リユース・リサイクル）の徹底はもちろん、廃棄物の発生量を邸別に把握することができるICタグや廃棄物適正処理システムの導入により、廃棄物の適正な管理や削減につなげています。


1

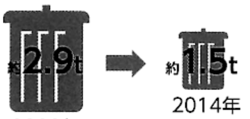

2

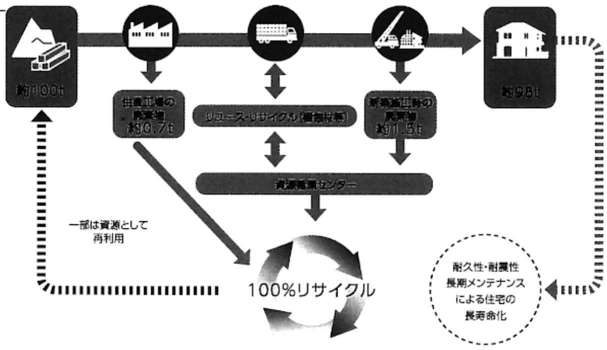

3

❶邸別ICタグ　一邸ごとの廃棄物の発生量を把握し、処理過程をより正確・迅速に管理。トレーサビリティを確保することにより、確実なリサイクル処理が可能になる廃棄物適正処理システムを導入しています。
❷重量測定　廃棄物が適正に処理されているか、重量により管理しています。
❸資源循環センター　施工現場での建築副産物を工場で各種類別に集積し、リユース、リサイクルすべく処理工場へ搬出します。

「自然界への建築廃棄物の排出ゼロ」の取り組みについて

建築廃棄物排出ゼロとは、住宅の新築・リフォームなどを通じて廃棄物の削減を目指すものです。たとえば、住宅1軒は約100トン（延床面積140㎡のダインコンクリート住宅の場合）の資源から、さまざまな部材を生産し施工することで完成します。一連の過程で、工場での部材生産時に約0.7トン、施工時に約1.5トンの「廃棄物」が発生しますが、家づくりで発生する廃棄物を埋めたてや単純焼却することなく、資源として100%リサイクルするゼロエミッションを実現しています。



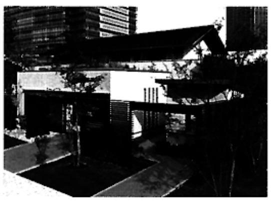


環境技術を駆使したさまざまな施設が集結「エコ・ファースト パーク」

関東工場に近接した「エコ・ファースト パーク」は、快適で地球環境にやさしいさまざまな住まいのカタチを体験し、学び、研究する施設。先人の知恵や先進の環境技術を駆使した「サステナブル デザイン ラボラトリー」「ゼロエミッションハウス」「観環居」の各施設をはじめ、「資源循環センター」（上記参照）や「5本の樹」計画の庭で構成されています。


サステナブル デザイン ラボラトリー
街中でも四季を楽しんだり、光や風をとり入れたり、自然との共生を先人の知恵に学び、次代の住まいを考えます。


ゼロエミッションハウス
「エネルギー」「水」「食糧」の自給自足をめざすとともに、移動をサポートするモビリティなどの最先端技術で快適な暮らしを実現します。


観環居
離れて暮らす家族の様子などがわかる先進のネットワークや電気自動車の活用と、懐かしい自然の心地よさが両立した木の家づくりです。

UE presentation

Reduction, Reuse, and Recycle of Natural Resources

Together with the factory, the construction site

The Resource Recycling Center dedicated to cello emissions.

Resource Circulation centers work hand-in-hand

with factories toward zero-emission of building Waste.

We will promptly promote new resource recycling initiatives, establish resource recycling centers at each plant, and

Zero emissions of the gate (production, new construction, after-maintenance, and renovation). Each

Up to 80 types of building waste generated in factories are sorted at resource recyclingcenters. 3R(Redue)

not only thoroughly recycle waste, but also allows you to grasp the occurrence of waste by residence.

By introducing tags and waste disposal restems in I, we are able to properly manage and reduce waste.

(16) By HouseI| CKotag Understands when waste occurs for each house, and manages the processing week more accurately and quickly. to ensure traceability.

In addition, we have introduced a waste properly treated silestem that can reliably cycle process.

Weight measurement: Waste is properly treated or managed by heavy ink.

@ Resource Recycling Center The building by-products at the construction site are collected at the factory for each type and transported to the processing plant for reuse and recycling.

[Zero emission of building waste to the natural world]Initiatives of Foot Source Housing Parts Production Transportation Construction New Housing

Zero building waste emissions are, through new housing and renovations,

to reduce waste. For example, a house is about 100 tons(fordyne concrete houses with a total floor areaof140mf)

It is completed by producing and constructing various parts from the resource.

approximately 0.7 tons at the time of production of parts at the factory, and

1.5 tons of[waste]is generated, but the disposal generated by the house building

100% as a resource without burying things or simply incinerating Lisa

Zero emissions

This

And

Some of them are resources.

I have realized. Reuse with withered,

/ Ming/Son/Son/Blue

100% recycled im

2014 BuriedK, AALes, Long Life

2000 Sei!Yan

in the

A variety of facilities that make full use of environmental technology [Eco-First Park]

In close proximity to the Kanto Plant,

"St Park" is a comfortable and global environment.

a variety of friendly housing to experience, learn, and study in the The wisdom of our predecessors and advanced environmental skills

Sustainable Desa using art

In Laboratory. Zero Em

"The House" |Kanring IiFacilitiesof

Resource RecyclingCenter]| SoTe

(See above)or theFive.Book Tree| Sustainable Design Laboratory Zero Emission House

Consists of a garden. If you play four grasses in a thousand, or try to be self-sufficient in light and wind, and energy[water] and food,you can see how families live away from you.

J. And the use of the most networks and electric vehicles, such as mobility to support mobility, and the use of electric vehicles, both in the knowledge of the predecessors of the coexistence with nature, and nostalgic

and think about the next generation of housing.   We realize comfortable living with advanced technology. Presentation 9752Close9" between ro

まのUE呈

Reduction, Reuse, and Recycle of Natural Resources

工場と一体となって、 施工現場の

セロエミッションに貢献する資源循環センター。

Resource Circulation centers work hand-in-hand

with factories toward zero-emission of building Waste.

いち早く新しい資源循環の取り組みを進め、 各工場に資源循環センターを設置し、 業界初の 4部

門 (生産・新築施工・アフターメンテナンス・リフォーム) のゼロエミッションを達成しました。 各

工場で発生する27 種類の建築廃材を、 資源循環センターで最大 80 種類へ分別。 3R (リデュー

ス・リユース・リサイクル) の徹底はもちろん、 廃棄物の発生時を邸別に把握することができる

Iにタグや廃棄物適正処理レステムの導入により、 廃棄物の適正な管理や削減につなげています。

|

3

|　　MHR

1　　　|

⑯邸別I|Cこタグ ー邸ごとの廃棄物の発生時を把握し、 処理週程をより正確・迅速に管理。 トレーサビリティを確保することに

より、 確実なりサイクル処理が可能になる廃棄物適正処理シレステムを導入しています。

の重量測定 廃棄物が適正に処理されているか、 重墨により管理しています。

@資源循環センター 施工現場での建築副産物を工場で各種類別に集積ししリユース、リサイクルすべく処理工場へ搬出します。

1に

[自然界への建築廃棄物の排出ゼロ| の取り組みについて 足源　　　住宅部材生産　　　輸送　　　施工　　　新築住宅

建築廃棄物排出ゼロとは、 住宅の新築・リフォームなどを通じ　　　ーーー　　　昌

て廃棄物の削減を目指すけものです。 たとえば、 住宅 1 軒は約

100トン (延床面積140mfのダインコンクリート住宅の場合) の

資源から、 さまざまな部材を生産し施工することで完成します。

一連の過程で、 工場での部材生産時に約0.7トン、 施工時に約

1.5トンの [廃棄物]」 が発生しますが、 家づくりで発生する廃棄

物を埋めたてや単純焼却することなく、 資源として 100%リサ

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環境技術を駆使したさまざまな施設が集結 [エコ・ファースト パーンク」

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設。 先人の知恵や先進の環境技

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ションハウス」 |観環居] の加施設

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(上記参照) や「5本の樹| 計画の サステナブル デザイン ラボラトリー ゼロエミッションハウス 居

庭で構成されています。 千中でも四芝をしんだり、 光や風をと 「エネルギー [水」 「食糧] の自給自足をめざすと 離れて暮らす家族の様子などがわかる先進の

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し 恵に学び、 次代の住まいを考えます。 先端技術で快適な暮らしを実現します。 お呈9752る閉9 」

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Extracts of translations of documents in Japanese via official translator. Daiwa brochure pages 7 and 8. All document was translated, this just represents a section of it. Translations were developed by Catriona Anderson in the city of Edinburgh between the years of 2016 and 2017.

Page 7 + 8

2 Creating three-generation homes for everyone

Getting to know the styles of three-generation homes

Search for the style of three-generation home that best suits your family and lets you live comfortably and harmoniously. Here, we introduce the three basic styles of three-generation home.

Separate cohabitation

Chosen by families…

- whose daily schedules are very different
- who have different values and lifestyles
- who want to observe each other's privacy
- who don't anticipate needing to support each other much, except in emergencies
- who don't want to rely on each other economically or in terms of lifestyle
- who have sufficient space on their land

The living spaces are completely separate, with room for both generations to live independently.

Separate installations for each family.

New family	Entrance	Living room	Kitchen/dining room	Bathroom
Family with childre	Entrance	Living room	Kitchen/dining room	Bathroom

p9

Joint cohabitation

Chosen by families…

- Who have different eating habits, and want separate kitchens
- Who want separate bathrooms, so they can take a bath when they like
- For whom sharing a kitchen or bathroom is more efficient in terms of the house plan, and more economical in terms of energy bills
- Whose lifestyles are different, but who can compromise in places
- Who will be sad if they don't have much opportunity to see each other

Families can live comfortably, sharing part of their living space, such as the entrance, living room, kitchen, or bathroom.

The entrance and kitchen/dining room only are shared, with the other installations separated by family (one example).

New family

Living room | Bathroom

Entrance | Kitchen/dining room

Family with childre

Living room | Bathroom

Integrated cohabitation

Chosen by families…

- Where the parents are both working, and the grandparents will help with childcare
- Who want to cut excess living costs as much as possible
- Who want a lively lifestyle
- Who often gather to spend time together
- Who don't have a lot of excess room on their land

A way of living that has become even more of a focus in modern times, where three generations live together under one roof.

Everything is shared.

New family

Family with

Entrance | Living room | Kitchen/dining room | Bathroom

p13

Page 9

2 Creating three-generation homes for everyone

((vertical text)) Value your separate ways of life, while living close enough that the soup won't cool.[23]

---

[23] It means they can live separately, but easily enjoy meals together at any time.

Getting to know
Separate Cohabitation

Separate cohabitation: Respecting each other’s lifestyles, with the peace of mind that comes with knowing you can meet straight away when necessary. For many people, this is the ideal way for three generations to live together.

((Speech bubbles - clockwise from top left))

We don’t have to worry about mismatched schedules or differences in our lifestyle habits.
(Wife in a new family, 59)

The reason we chose separate cohabitation was because our land was spacious.
(Husband in a family with children, 33)

We can maintain a moderate distance. We don’t have to meet if we’re too tired.
(Husband in a family with children, 34)

If we lived together, we would probably lose our privacy.
(Wife in a family with children, 33)

Page 10

Separate cohabitation

Separate your house completely,
and each family will have space for their independent lifestyles.

With this style, all living space including the entranceway is separated by family. Generally, the families’ living spaces in these three-generation homes are separated by upper and lower floor, or by left and right.

Merits
- Privacy is maintained
- Can easily be rented out in future
- Beneficial for tax

Disadvantages
- Few benefits in terms of construction costs
- More land and space necessary compared to other

Each family’s privacy is maintained, but with the peace of mind that comes with living together.

New families and families with children can live uninhibited, with the feeling of being neighbours, so this is recommended for three-generation families whose lifestyles and daily schedules are different. Popular opinions on the reason for choosing separate cohabitation were: “The privacy of each household is maintained,” and “It seems like we can maintain better relations living separately.” Each family can preserve their privacy, while gaining “the peace of mind that comes with living together.”

The construction costs are relatively high, and a spacious plot of land is required.

Compared to other cohabitation styles, separate cohabitation has few economic benefits for a three-generation family. The construction costs are fairly expensive compared to other cohabitation styles, and as the rooms and installations are doubled, a wide space is needed. It also means the energy bills—electricity, gas, and water—and cost of living are required for each separate household. However, there are benefits in terms of tax (see p16).

Planning point

A communication door or space can be installed to facilitate communication between the two families

With separate cohabitation, where the houses are completely separate, you may want to devise a plan for the house that stops the two families losing touch with each other. The question of how to allow people to come and go and facilitate exchange and cooperation between the two families is an important point when creating a house. It might be good to create a communication door, or a space where both families can spend time. If you’re thinking of setting up a communication door, we recommend the type with a lock, which also has tax benefits.

Page 11

2 Creating three-generation homes for everyone

((vertical text)) Live connected with your family, but with moderate distance.

Getting to know
Joint Cohabitation

Joint cohabitation: There are various ways of living to suit your family’s lifestyle. With this lifestyle, you can enjoy the benefits of a large family, while also keeping some distance when necessary.

((Speech bubbles - clockwise from top left))

We have two bathrooms, so even if I come home late, I don’t need to worry about what time I can take a bath.
(Husband in a new family, 63 - separate kitchen and bathroom)

I’m glad we didn’t have to completely separate our two families. If anything happens, they will come over. I feel reassured knowing that someone is there.

(Wife in a new family, 53 - shared entranceway only)

Our eating habits are quite different, so we wanted to do meals separately.
(Wife in a family with children, 44 - separate living room, dining room, and kitchen)

We want to prioritise our privacy, rather than practicality.
(Husband in a new family, 63 - shared entranceway only)

Page 12

Joint Cohabitation

Enjoy a comfortable lifestyle, sharing an entranceway, kitchen, living room, or bathroom

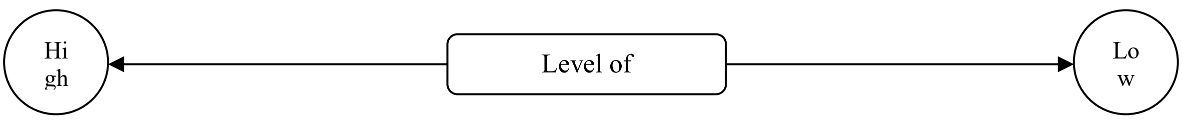
With this lifestyle, you keep part of the house separated by family, for example the entranceway and kitchen, and share part of the house between all three generations.

Joint cohabitation: An attractive balance between a lively household, and privacy.
With joint cohabitation, you can maintain a moderate level of privacy and independence, enjoy the benefits of having two families living together, and use your land efficiently.

Planning point

3 types of joint cohabitation houses, divided based on places where you want to maintain your privacy

What will you separate, and what which you share? “We just want the bathrooms to be separated by family,” “Our taste in cooking is different, so we want separate kitchens.” With joint cohabitation, the level of integration between the two families will depend on whether you want to maintain privacy for both families in spaces like the living room, dining room/kitchen, and bathroom. Discuss with your family about the spaces where you require privacy based on these three types, and plan a joint cohabitation house where you can live together comfortably.



The sharing family	The balanced family	The independent family
You don’t mind if the dining room, kitchen and bathroom is	You want to maintain a good balance between privacy and communication, and keep places	The highest degree of separation within the joint cohabitation type. The two families’ lifestyles,

<table>
<tr><td colspan="3">shared. However you want space where the two families can spend time uninhibited.</td><td colspan="5">where you relax, like the living room and bathroom, separate for both families.</td><td colspan="7">starting with their mealtime habits, are different.</td></tr>
<tr><td colspan="3">Living room only separate</td><td colspan="5">Living room and bathroom separate</td><td colspan="7">Only the entranceway is shared</td></tr>
<tr><td>Living room</td><td>Dining room/kitchen
Bathroom
Entranceway</td><td>Living room</td><td>Living room</td><td>Bathroom</td><td>Dining room/kitchen
Entranceway</td><td>Bathroom</td><td>Living room</td><td>Living room</td><td>Dining</td><td>Bathroom</td><td>Entranceway</td><td>Bathroom</td><td>Dining</td><td>Bathroom</td></tr>
</table>

Page 13

2 Creating three-generation homes for everyone

((vertical text)) An exciting and lively lifestyle! Twice the fun, with two households!

Getting to know
Integrated Cohabitation

Integrated cohabitation: With this style, the bathroom, kitchen, and entranceway are all shared between the families. This is a focus in the modern age, when “family ties” are increasingly questioned.

((Speech bubbles - clockwise from top left))

We never run out of topics of conversation.
(Wife in a new family, 60)

I’m away from home every day with work, so I chose this so I could request help around the house.
(Wife in a family with children, 30)

Grandpa teaches me things like how to wipe the table.
(Child, 6)

We don’t have to waste money on electricity and gas bills. I want to put that money aside for our children.
(Wife in a family with children, 34)

Page 14

Integrated cohabitation

Two families living together under one roof, a way of life increasingly focused on nowadays

A way of life dating from old Japan, where three generations live together and share all the basic living spaces, such as the living room and kitchen.

Merits
- Enjoy a lively lifestyle in a big family
- Keep down the construction costs and save on bills

Disadvantages
- Difficult to maintain privacy
- With different lifestyles and values, sometimes you need to

It’s easy to help each other with childcare and chores, and also to educate kids[24]

The greatest appeal of integrated cohabitation is that you can all enjoy spending time together. It’s easy to cooperate when it comes to childcare and chores, and in the modern day when households with both parents working are on the increase, the benefits of this system come into focus again. Another benefit to integrated cohabitation is that with three generations living together all the time and never far away, grandparents can also teach their grandchildren manners and culture.

Keep the construction and the running costs down

When building your house, you only construct the facilities of one family, so you can keep the construction costs down. And, because the kitchen and bathroom is also shared, you can save on the electricity and gas bills and the running costs. Integrated cohabitation is a lifestyle suited to the modern age in terms of economy and ecology.

Planning point

Devise a space with consideration for your privacy, where you can be yourself.

The liveliness of a large family is one of the attractive points of integrated cohabitation, but sometime you need your private time. Preserving the two families’ balance between privacy and communication is important. We recommend planning a home where “deepening the bond between the families” and “maintaining a moderate distance” are compatible, for example, by creating a second living room for your children.

Page 15

1 Three-generation families cohabitation column

I never knew that! Three-generation homes

[24] Literally: “to pass on/communicate the culture of the home”

Three-generation homes are deeper the more you get to know about them.
In fact, there are lots of unexpected realities to three-generation homes that will make you think, “I never knew that!”

I never knew that!

Three-generation home ideals and reality

The ideal is “everything separate”, but the reality is “shared”

Around 40% of all families living together in three-generation homes want the basic lifestyle spaces, the entranceway, living room, kitchen, and bathroom, to be separate for each family. However, a survey made it clear that when families actually build their homes, almost 60% of them share the kitchen. While the ideal may be “everything separate”, it seems that the reality is “shared.”
Around half of the families currently sharing everything also held the ideal of sharing everything. There are many families who actively want to share, with some saying, “If we’re going to cohabit, we want to spend time together.”

- Plan type ideals and realities

((left)) [Ideal plan]

43.1% Everything separate

((right)) [Actual plan]

55.9% Everything shared/living room only separate

Dark orange = Everything shared/living room only separate
Orange = Living room, dining room, kitchen only separate
Yellow = Entranceway only shared
Dark grey = Everything separate
Light grey = Other

I never knew that!

What about marriage circumstances with three-generations living together?

The number of cases of unmarried children living with parents is increasing

Today there are more and more people who remain unmarried, or who get married later in life. Amongst three-generation families living together, in close to 20% of all cases there is an unmarried child living with the parents. In these situations, people may feel hesitant about living with a sibling who is already married. However, if you plan the room arrangements carefully, it's possible to achieve a cohabitation lifestyle where everyone is happy.
Give consideration to things like flow planning, so that even if the unmarried child of the new family (grandparents) works on weekdays and comes home late, they can take a bath and go to bed without worrying about bothering the other families. If you maintain these sub-lines of flow, then even if someone gets married and moves away from the family, the open room can be converted and used for leasing, or as a room for hobbies.

((top to bottom))

New family (grandparents)
Family with children
Unmarried child of the new family

Page 16

I never knew that!

Do the husbands of society aspire to be "Masuo-san"?*

((*Masuo-san is a character from a well known Japanese manga called Sazae-san. He is the husband in a married couple who live with the wife's parents. So "Masuo-san" is shorthand for "a husband who lives with his wife's parents".))

"Close cohabitation" between mothers and daughters is actually desired by the daughters' husbands

The proportion of separate kitchens for families who live with the husband's parents, and shared kitchens for families living with the wife's parents, is increasing. In recent years, mothers and daughters living in friendly cohabitation have become a point of focus. You might think that many mothers and daughters want to live in close cohabitation, in "joint cohabitation" or "integrated cohabitation" homes. However, looking at the survey results, surprisingly it is actually the husbands moving in with their wife's parents who hope for this the most. It turns out that the husbands of society actually aspire to be "Masuo-san".

- Ideal plan types: "Those desiring a shared kitchen*"

((left to right))

36.9%	33.0%	30.8%	55.3%	31.5%	17.9%
Husband in new family (grandfather)	Wife in new family (grandmother)	Husband in family with children (living with husband's parents)	Husband in family with children (moving in with wife's parents)	Wife in family with children (living with wife's parents)	Wife in family with children (moving in with husband's parents)

*A survey was carried out asking participants to choose between a separate kitchen and a shared kitchen.

I never knew that!

Are there tax benefits to three-generation homes?

There may be tax benefits for the two households

When it comes to homes, you will ordinarily be taxed with real estate acquisition tax and property tax. However, three-generation homes that meet certain conditions may be able to receive benefits. Also, as Daiwa House "xevo" meets the standard specifications certified by the Ministry of Land, Infrastructure, Transport and Tourism in "Certified long-life quality housing," they receive other tax system benefits compared to general housing.

- Reduced real estate acquisition tax
  If over 50m^2 and under 240m^2
  Tax amount = (estimated property tax - deduction) x 3%
  The deduction is ¥12 million (or ¥13 million for certified long-life quality housing) per household. Furthermore, in cases where there is no coming and going between the two houses, so-called complete separation, the two households can receive further deductions.

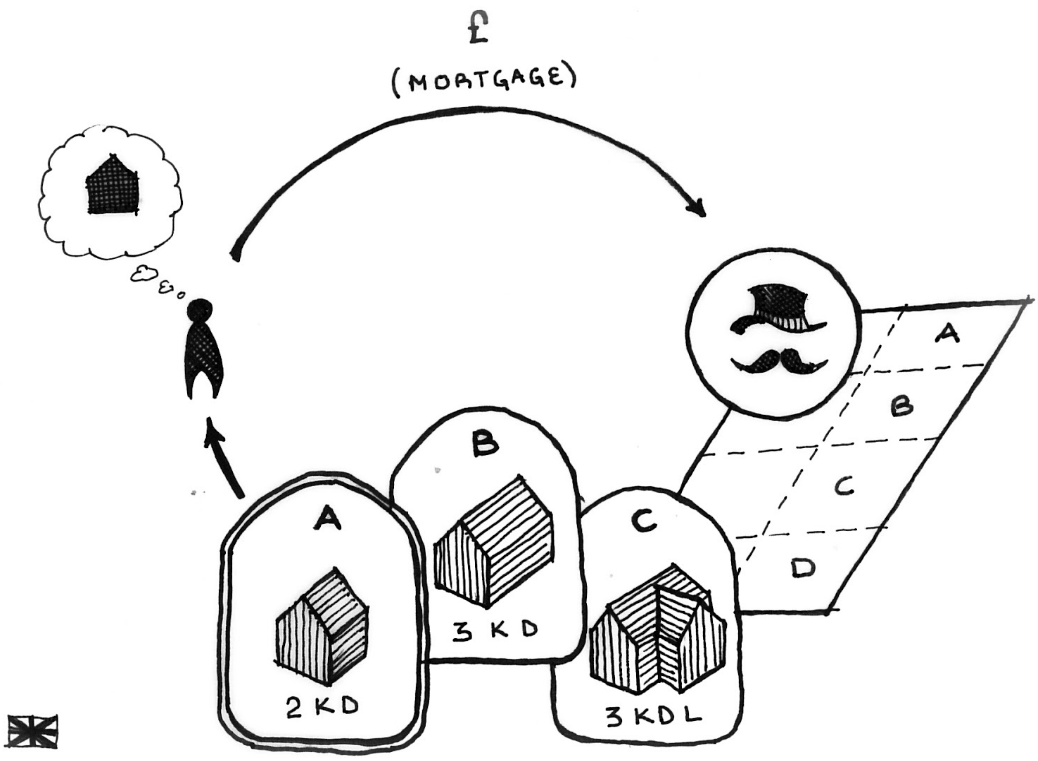
- Reduced property tax on the land
  An area of up to 200m^2 of land for one home is treated as a small-scale residential site, and the standard property tax is reduced by 1/6, with the standard city planning tax reduced by 1/3. Furthermore, in cases where there is no coming and going between the two houses, so-called complete separation, the two households can receive further deductions.

- Reduction of the inheritance tax on the land (in special cases such as small-scale residential land)
  If the portion of the land (up to 330m^2) in the name of the deceased is inherited by an inheritor living in a cohabiting three-generation family meeting certain conditions, the estimated value of the land can be decreased by 80%.

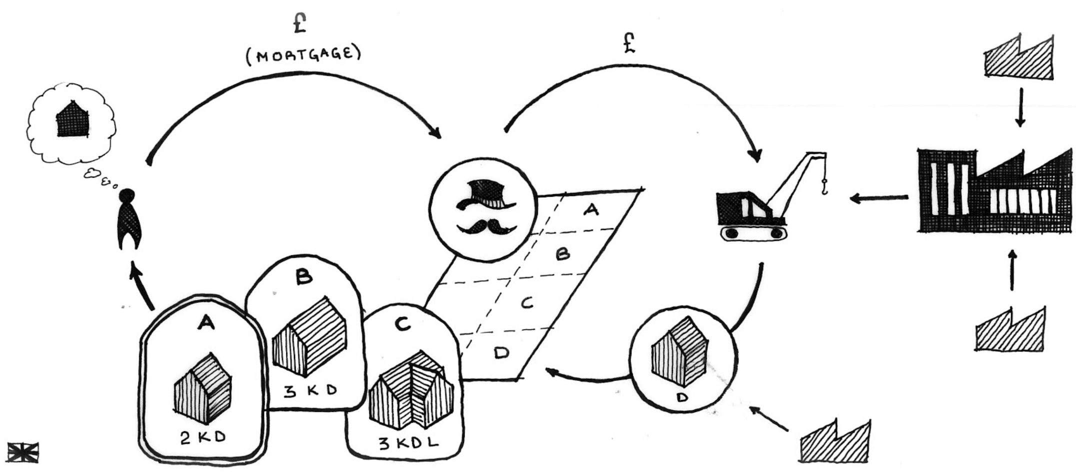
  * Depending on the individuals, there may be cases where there are no benefits.
  *Other municipalities may have their own independent benefit systems.
  *For more details, please speak to our staff.
  *The stated information is correct as of December, 2014.

Previous diagrams

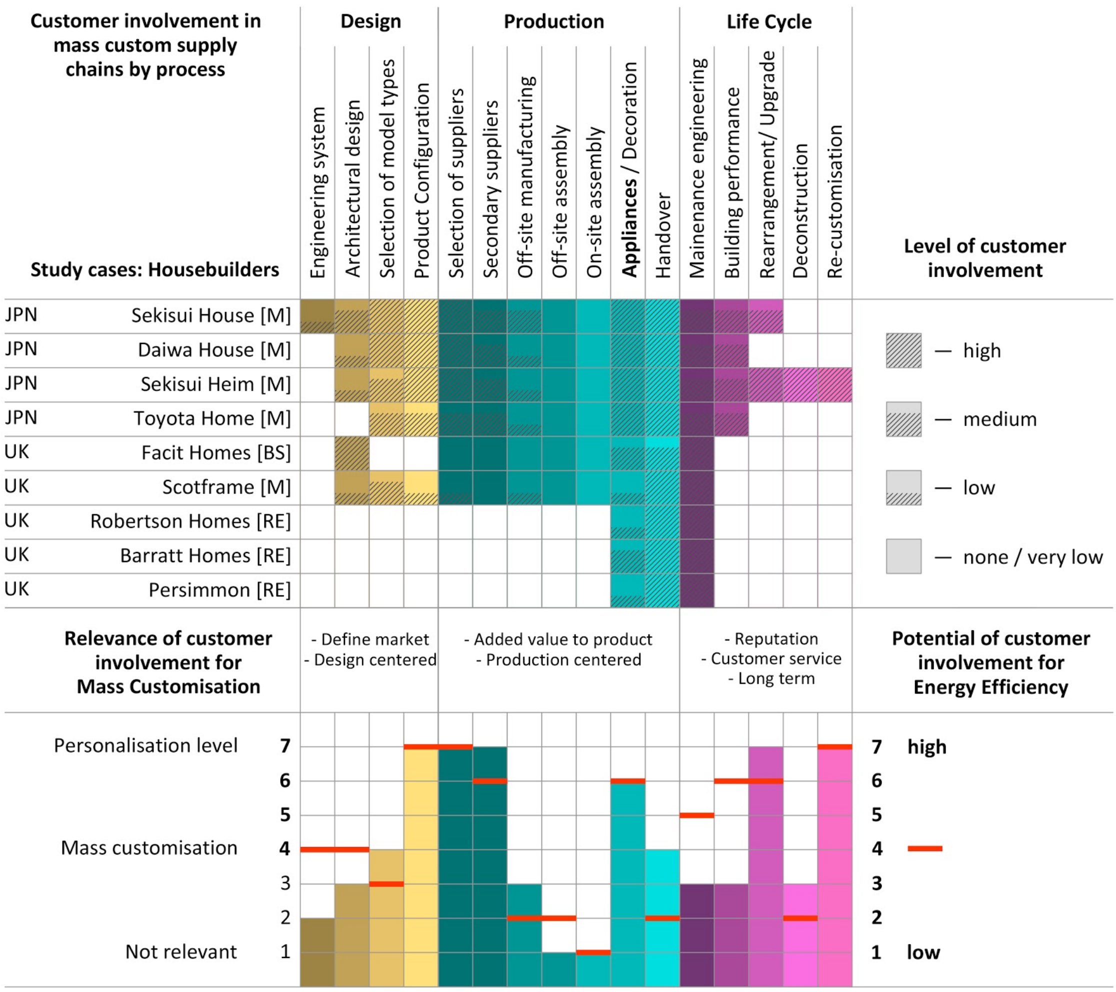
Exmples of the development of diagrams that were not used in the thesis.



Buying process UK



Buying process UK 2

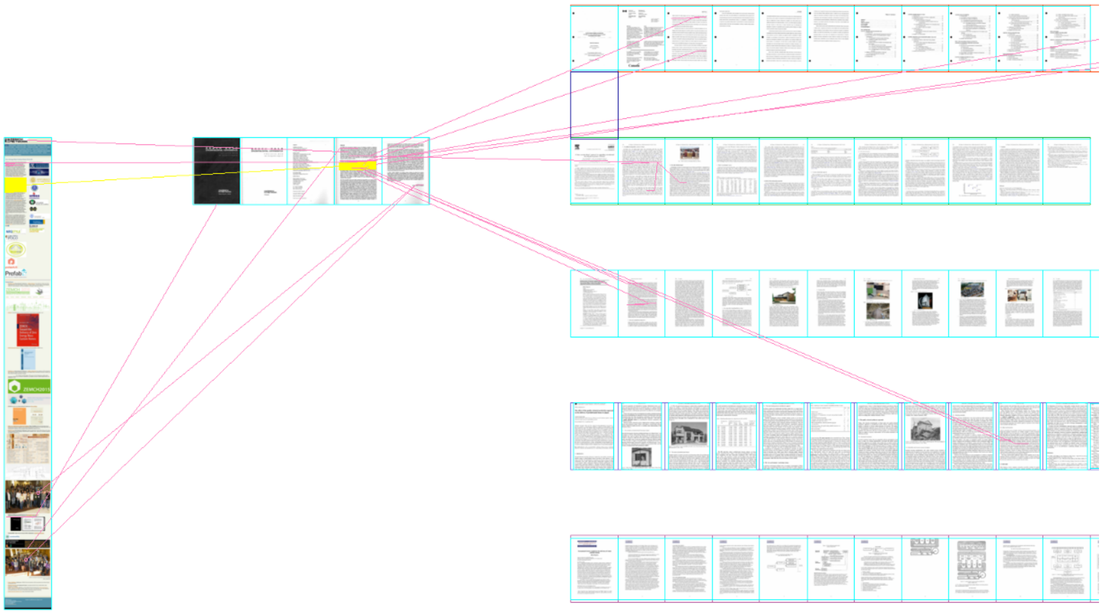


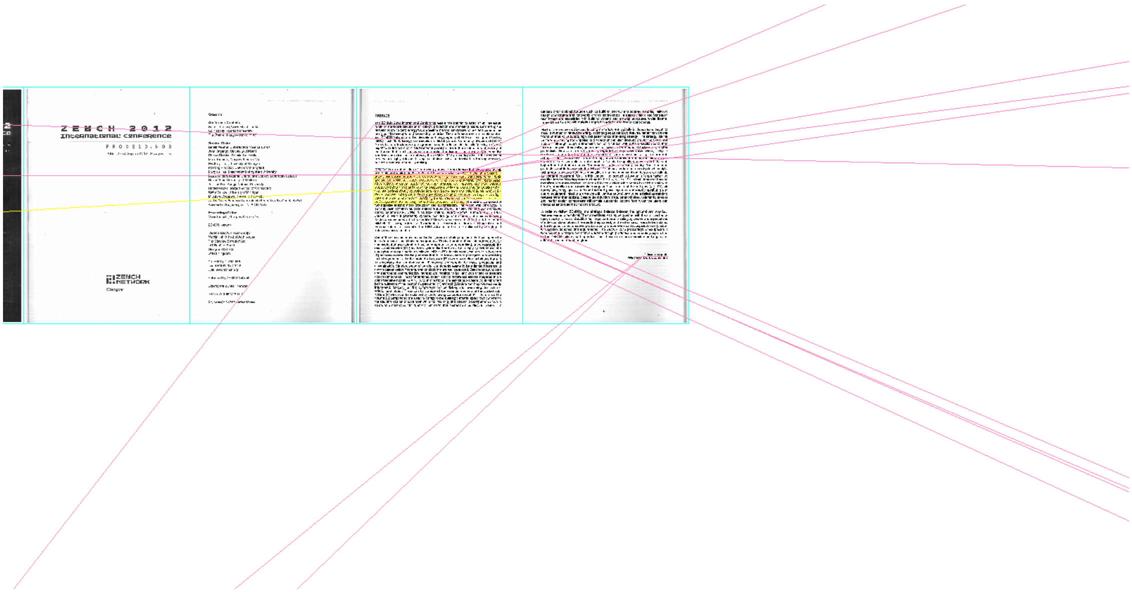
Companies comparison

Visual referencing tool and virtual archive

Images of CAD files displaying scanned bibliography and references to the body of text

ZEMCH and Noguchi's texts




ZEMCH 2012
International Conference
PROCEEDINGS
ZEMCH NETWORK
Glasgow
PREFACE

Additional texts

Short story used as an analogy to describe the mass customisation selling process used by Japanese companies such as Daiwa House. The text has kept in the original format to respect the arrangement of image ant text.

The cat that designed his house

This is the story of the 'Kurokawas', two families that have been living next to each other in a neighbourhood in Tokyo for a long time and decided that is time to buy new homes.

It would be hard to find two families more alike than the Kurokawas in all of Japan. The fathers of the families are identical twin brothers in their mid-forties owners of a couple of small pharmacy stores. They both have medical degrees from the same university and have season tickets for the 'Yomiuri Giants' baseball team. They look so alike that even their relatives find hard to distinguish them from each other. They also got married on the same day to a couple of women that work as delivery girls for a company that supply pharmaceutic products. The mothers have been best friends since primary school and keep on meeting weekly to practice the violin. Coincidently, each family have a young girl. Both kids go to the same school and are good friends. One can say that they are practically identical families.

Probably the only difference among them is that one family owns a cat. A beautiful young grey 'Maine Coon' that they rescue from their backyard a couple of years ago and has turned into an essential member of the family.

The Kurokawas agreed on replacing their existing houses with new ones to avoid changing the neighbourhood and remain living next to each other. After analysing their options, they decide to use the services of a nationally known house manufacturer, because this way, they feel secure about the construction costs and timings.

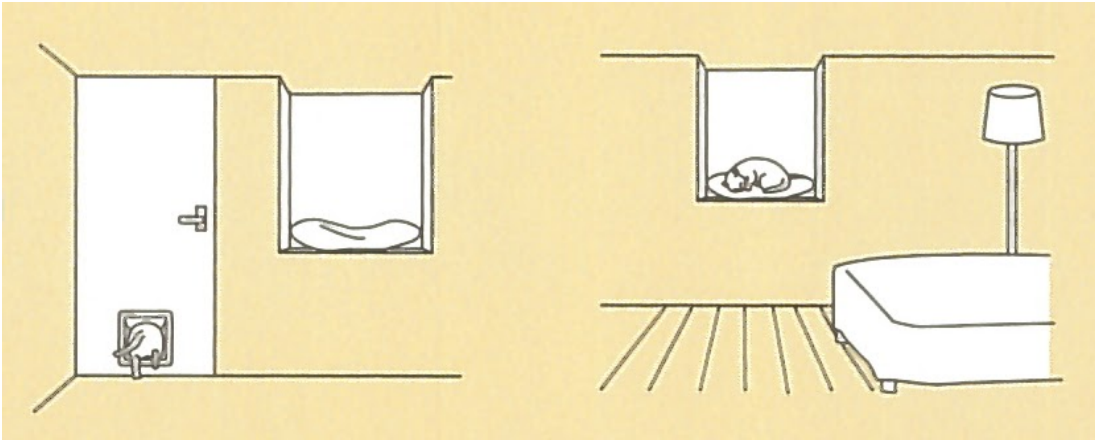
On a Saturday, the families travelled together to the company's selling centre decided to get their new house. On their arrival, they were welcomed by a couple of selling agents who guided them through the facilities and showhomes. Already convinced, each family started the buying process separately. Once all of it was done, both families met at the exit of the selling centre and travel back home.

For a few months, the families needed to move to temporary accommodations to allow the demolition and construction of the new houses. But the delivery day arrived on time, and they were ready to move in.

The families met excitedly in front of their new houses. But sooner rather than later, they realised that there were significant differences between both houses, something unexpected but fascinating. Intrigued by this happening, they started exploring the dwellings to identify all these dissimilarities.

The first thing they noticed was that the windows were different; while in the first house they were aligned with the walls, the second house had a prismatic window projected to the outside, and their sliding doors were subdivided into more segments than in the first house.
Once inside, they noticed that the second house had an extravagant arrangement of shelves over the living room, like floating platforms. They also saw that the flooring was different; the first house had a texturised wooden deck in the common areas and continuous carpet in the bedrooms, while in the second house the flooring was very smooth and the carpet in the bedrooms was tiled.
The differences were easily spotted all around the second house, their bathroom had an additional sink, the wardrobe arrangements were different, it had more extractors, and all the internal doors had small openings at the bottom.

The father of the first family incapable of understanding why the houses were so much different approach his brother and asked him about it, pointing out a niche in one of the bedrooms that they did not have in their house as an example. But before his brother was able to answer anything back, the fluffy cat jumped into it, spun slowly twice and confidently laid down purring.



The brothers turn to each other and start laughing. There was no need for answering the question, it was clear who was in behind this differences. In the meanwhile, the cat was confidently sleeping as if he proudly knew he was responsible for the design of his house.

THE END

...

But what does this story has to do with mass customisation, and especially, with energy efficiency?...

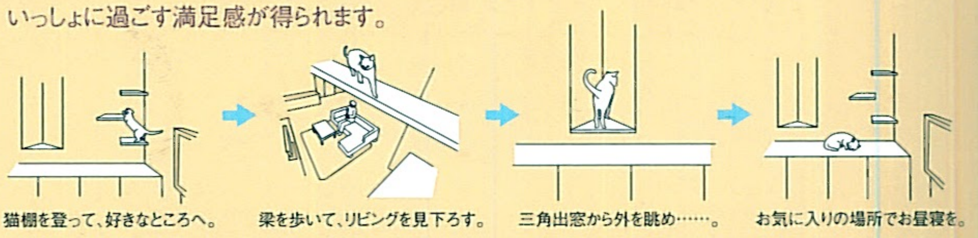
I use this story as an analogy to explain how mass customisation (MC) approaches could be reflected in the design and performance of houses and the user's daily life. MC is generally understood as a strategy used only to provide customers with variability; which up to a certain point is true, but does not represent any advantage than providing variability by itself (if consider of any). The beneficial aspect that MC can bring to any production process is the promotion of better practices by informing customers about the significance of the different options provided, especially regarding performance. Therefore, applying MC to housing could increase the production (over the total) of more energy efficient dwellings, considering that energy efficiency is an increasing social need and desire that people relate to sustainability, thermal comfort and reduction in bills.

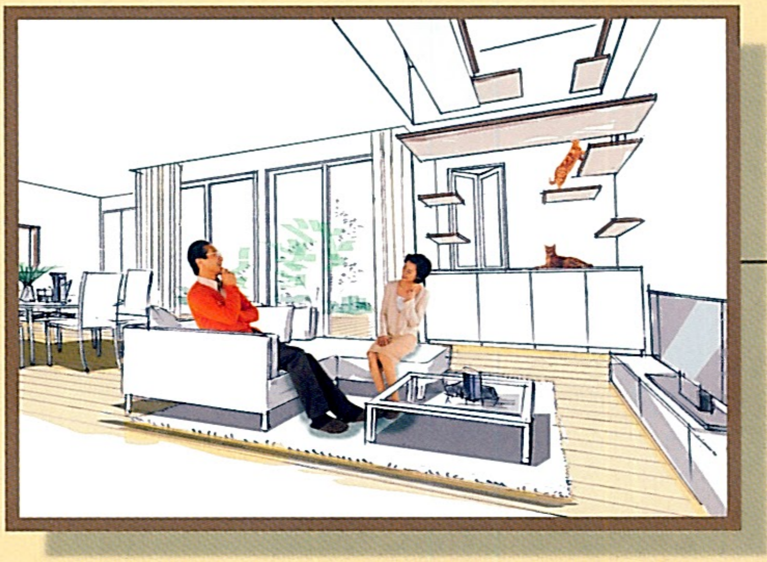
The story of the cat is obviously a fictitious situation but based on real customisation options that Japanese house manufacturers, as 'Daiwa House', provide to their customers. The prismatic window and subdivisions in the sliding glass doors are openings that the cats can use to get in or out the house. The *floating* shelves and escalated furniture are activity centres for the pets, similar to what is known as ‘cat castles’. The smooth flooring, tiled carpets and extractors are easy cleaning alternatives that also reduce the fur accumulation. The small openings in the doors and niches are other appliances designed around the cat figure. Daiwa House provides multiple additional appliances for pet owners— vigilance cameras, sleeping areas, areas subdivisions and rugs— not mentioned in the story because few examples were enough to prove the point.

健康環境の向上

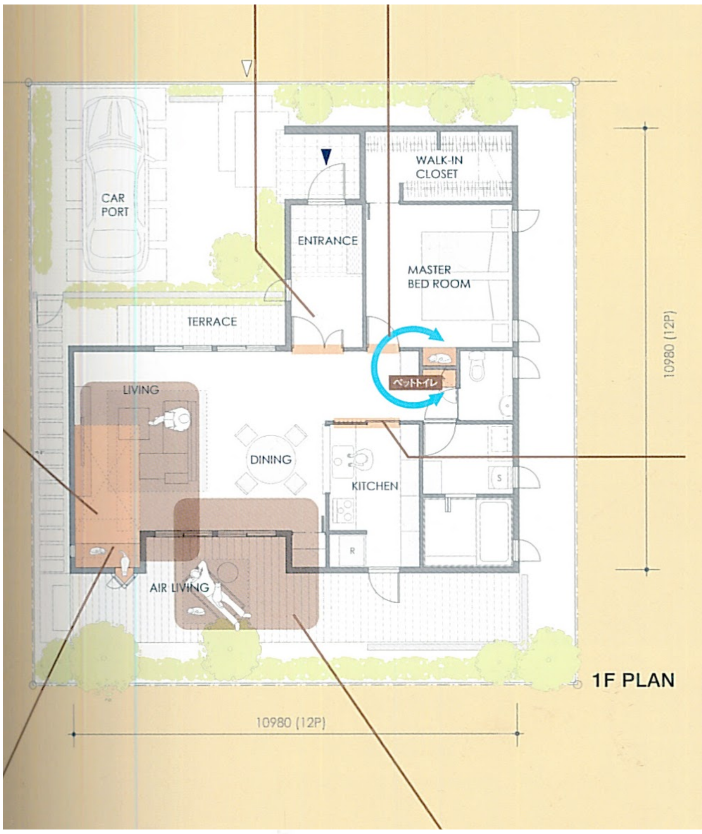
猫たちがワクワクする斜め天井でつくった高い場所。好きなところへ登って、運動不足も解消。

ペットの居場所を用意するだけでなく、高いところへ登りたがる猫の習性にあわせて、猫棚やキャットウォークを設けたプラン。猫の居場所はキッチンからも眺められ、いつもいっしょに過ごす満足感が得られます。





行きたくなって起きる。　トイレで用を足す。

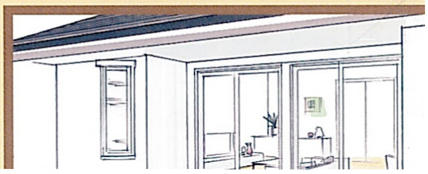


1F PLAN

家庭内事故予防

キッチンはインテリアドアでしっかりと仕切ります。

ペットにとって危険がたくさんあるキッチンへの立ち入りをストップできます。家族にとっても料理が効率的にでき、ペットが生活のルールを学びやすいように工夫しています。



床の滑りを防止してペットの足を守る。
タイルカーペット

置き敷きなので、家具を動かさず並べて置くだけで簡単に敷けて、汚れたら部分洗いができます。防ダニ加工でペットの大敵、ダニの繁殖にも対応しています。

輻射熱なのでホコリを巻き上げずに、暖かく。

床暖房システム DOG CAT

遠赤外線で暖める“輻射熱”と、床面から直接伝わる“伝導熱”の相乗効果で、お部屋をムラなく暖めます。お部屋の空気はクリーンなままで、温風でホコリを舞いあげることがありません。ペットが自由に動き回れるリビングやダイニングに設置すれば快適。「電気式」と「温水式」の2タイプを用意。

※ペットのハウスを床暖房の上に設置すると、熱中症の原因となることもありますので、ご注意ください。

小型犬が手軽に洗える。

マルチシンク DOG CAT

玄関などの土間スペースに設置して、小型犬や猫のシャンプーや散歩帰りの足洗に重宝するシンクです。シャンプーだけでなく、ガーデニング用品やアウトドア用品も洗えます。水ハネ対策に周囲の壁にはサニタリーウォールを設けてください。

間口1Pタイプ
吊戸:W-IPU-08EW
シンク:W-IPB2-08PWBN(-S)
ワゴン: IP-BB-FCW60A

正面

収納例

シンク形状

Daiwa House presents the pet design options through multiple brochures and possibly allow their customers to see (try) one-to-one examples on their showhomes and selling centres. However, this marketing strategy not only applies to pet appliances, but it is an integral part of their design and selling process.

Check Point

□わが家にぴったりの調理機器を知る

湯沸かし実験や操作体験を通して、ガス・電気それぞれの熱源の特徴や、わが家にぴったりの加熱機器が見えてきます。

□キッチン設備を心ゆくまで比較実験

シンクからワークトップの天板、食器洗い乾燥機や浄水器まで、さまざまなキッチン設備を確認します。

Check Point

□４つのキッチン空間のサイズを検証

アイランドキッチンやL型キッチンなど、4タイプのレイアウトのキッチンで、家族の食生活に合わせた空間の広さなどを確かめます。

□通路幅や収納高さの使い勝手をチェック

可動式の通路幅や吊戸を動かしながら、作業しやすい通路幅や収納の高さをチェックします。

※使いやすい収納高さを検証できる人体スケールのパネルは、「パーツランド」に展示しています。

Check Point

□ 車いす使用時の作業性を検証する

高さを調節できる流し台を使って、車いす使用時の設備機器の使い勝手や日常行為のしやすさなどを検証します。

※可動壁を用いた通路幅体験は
GARO 体験コーナーで行います。

Check Point

□ G A R O体験

特殊な装具を使って一般老化、妊婦な
何気ない動作の大変さが身にしみて分か

□ 目と耳の老化体験

老化現象に伴う目と耳の機能変化を疑
して、見え方・聴こえ方への配慮の大
実感します。

Check Point

□昇り降りしやすい階段を考える

寸法や勾配の異なる3種類の階段を使って、昇降のしやすさの違いを確認。安全で使いやすい階段の「なるほど」が見えてきます。

□心が踊る楽しい階段

吊り階段や勾配が変化する階段など、ちょっと変わったタイプの階段を体験します。

This type of interaction between the company and the customer is common in the majority of house manufacturers in Japan and covers a full range of design aspects, from kitchen arrangements to acoustic insulation. Their selling centres display multiple options of solar panels, heating systems, insulations and other systems related to energy efficiency. Future-users are guided with trials and different mediums of information that facilitates their decision process.

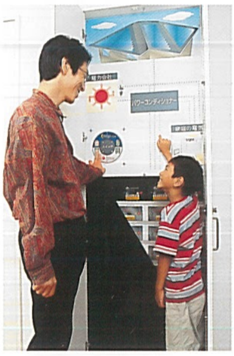
Check Point

□生活用水をかしこく蓄える

被災時に最も困るのは、トイレの洗浄などに使う生活用水の不足。その確保に役立つ雨水タンクや貯湯式温水器をご紹介します。

雨の恵みを活かす雨水タンクを体験

□エネルギーを創って蓄える



太陽光発電で創った電気エネルギーを貯めておける蓄電池をご紹介。照明や調理、携帯電話の充電など、被災時に必要な最低限の電源を確保できるシステムです。

蓄電池を併用した太陽光発電のメリットが分かる

Check Point

□わが家を守るための防犯意識を育む

普段の何気ない暮らし方を振り返り、防犯意識を診断。わが家の安全を脅かす犯罪に対する心構えが見えてきます。

あなたの防犯意識は高い？低い？

□「見える・守る・知らせる」仕掛けを体験

侵入盗に対する防犯対策の基本、「見える防犯」「守る防犯」「知らせる防犯」の3つの視点に基づいた防犯対策の数々を体験します。

狙われにくい家の仕掛けがまるごと分かる

I believe that the relationship between MC and energy efficiency comes in a natural unforced manner, where MC is a design strategy that helps people to obtain products closer to their wants and needs, and energy efficiency (as part of a more sustainable way of living) has turned into an increasingly social desire. This relationship between MC and energy efficiency highly depends on allowing/making the future-users understand the significance of their decisions, which not only should facilitate their decision-making process but promote customer satisfaction and more sustainable practices.

H is for Home

The work presented in here was presented in ‘AHRA Annual Research Student Symposium’, named as ‘H is for Home’ by Pablo Jimenez-Moreno and Hafsa Olcay. This study was conceived by all of the authors. I, Pablo Jimenez-Moreno and the Author of the thesis, carried out the writing of the paper and collection of material. The text has kept in the original format to respect the arrangement of the text and its meaning.

H is for Home

[by alphabetical order]
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Abstract

In this study, we aim at questioning what the use of the term 'home' over 'house' in representations might suggest about the relationships around dwelling with regards to its (potential) occupants and companies that design and construct dwellings. First, we seek to show whether the presupposed distinction between 'home' and 'house' can be identified universally. Then, we use the availability of such distinction in English to examine how the use of the term 'home' informed the representation of dwellings, with a specific focus to the relationships that are aimed to be explored by traveling from several artistic works irrelevant to construction industry to those produced by construction companies to present their products.

A virtual archive of images was developed simultaneously to the text as a visual research device, which did not only serve as a presentation tool, but also allowed us to envisage all the images collected in one display creating visual connections. A chiasmus was generated between the creation of the digital archive and the text, where an action on one was reflected on the other and vice versa. Aiming at engaging the readers [and the spectators] on thinking about the concept of home throughout, this study concludes by posing questions about the pretended relationships claimed by the forms of representation, and raising concerns regarding the ambiguity around the idea

of home that might lead to undesirable directions related institutions can take in dealing with dwellings.

Keywords: house, home, construction, representation, advertisement

Introduction

The linguistic distinction between the terms ‘house’ and ‘home’ in English facilitates examination of the ways in which dwellings are represented first by a language, and then, in other forms of representation. Not in every language do we find correspondents to the term ‘home’ as an arguably different concept from ‘house’ as in English. In some languages, we find more than one word which stand for dwelling, but are not prone to everyday use, as is ‘home’. The range of difference between linguistic representations of dwellings is not limited to this. Studied famously by Whorf, a Native American language called Hopi language shows notable differences to English in categorizing things (i.e. Whorf 1938). Abel (2015) notes that these differences in Hopi language are also conceivable in the conceptions of the built structures, and that there is one word which corresponds to all buildings whether they are houses or not (p. 19). The prevalent use of both ‘house’ and ‘home’ in English, however, allows us to examine the use of these two concepts within various contexts. Home, allowing subjective interpretations of a dwelling, seems to defy concrete definitions and allows creative exploration of the intimate relationship between people and place. Despite the broad literature on the concept, ‘home’ is still a productive area of research to understand our relationship with the world, and the ways in which the term was interpreted and used by variant actors. If we consider home as a “process” as Miller (2001) suggests, the preference of the term ‘home’ over ‘house’ by the agencies involved in the production of the house/home might suggest certain perceived relationships regarding the (potential) occupants as well as other actors involved in this process, if there are any. Our interest within the scope of this study is probing the role of agencies in making of home by examining the use of the term ‘home’ as a form of representation by industrial companies and reflecting on the probable consequences of such use.

It depends … *todo es según el color del cristal con que se mira*

In 2011, the Swiss artist Marianne Mueller presented at the Peabody Essex Museum the installation called *“Any House is a Home”*. The exhibition consisted of a collection of antique furniture distributed along the gallery facing the wall (Mueller, 2017). A series of photographs and images of her private collection were arranged in juxtaposition with the selected furnishing, sometimes emphasizing the pictures and other times collocated in secluded places like high corners or just some centimetres over the floor. There was an eclectic combination of old images of stairways and Japanese temples with new photos of domestic urban details like fences, windows and chairs. The memories behind the elements were the ones that narrate the story of the inhabitants, a sense of melancholia and attachment to a place, the house. The exhibition was named after a line from a poem written by Gertrude Stein. In the poem, there is a section called *Pears* which ends with the following lines:

Seating. Little manners.
When I asked everybody to sit down, they were annoyed.
Please be at wax matches.
Please beat. Please beat.
I cannot express emotion.
Any house is a home.

This poem was written during the 1st World War and it seems to indicate the detachment of Stein from places that homed her for some period of time. In her emotional state which she “cannot express”, it seems that the distinction between house and home is not evident for Stein anymore, so what matters here, seems to be independent of the physicalities of a house. Mueller defined ‘home’ as the meaning given to “that which brings people to an inner or emotional life” (Lisa Kosan, 2011). Her work pretends to show the extents where a house can be considered a home, for Mueller this relies on the emotional dimension given to the architecture and furniture–regardless of the house’s age, material or style. She also states her belief that not *all* houses are homes, elevating the conception of a home from that of a simple House (Kosan-Mueller, 2011).

At this point it seems that the making of a home is tied to its owner and to her constant accumulation of objects and memories, along with her capacity of feeling. So, what would be the role of other actors in conception of a home? Curiously for her exhibition, Mueller collaborated with the Johnston Marklee architectural firm to develop a twisting, two storey ziggurat that served as a monumental frame for her images and photographs (Geiser 2012, 43). In Johnston and Marklee’s work, the domestic space was predominated. Mueller also collaborated in the design of their book, where, using a similar process of collection and creation, she elaborated on a series of images taken from Johnston and Marklee’s buildings and collected from their personal archives and photo albums. These final images introduce the enclosure of the book, which was ‘coincidentally’ titled:

HOUSE IS A
HOUSE IS
A HOUSE IS
A HOUSE
IS A HOUSE

The title of the book, avoiding the term ‘home’ but preferring the use of ‘house’ instead, is also an allusion to another writing by Gertrude Stein called *Sacred Family*, which poetically states, “*Rose is a rose is a rose is a rose.”* Both the title of the book and the poem suggest multiple usages and interpretations of the same word. This metaphor is used by the authors of the book to refer to the different types, scale, and character presented by the houses (Geiser 2012, 45). The statements *“a house is a house”* and *“any house is a home”*, do not necessarily mean that the ways in which a house is conceived affect its status as a home. In fact, Mueller’s purposely undefined message could be better interpreted as her way of *visualising* ‘home’ as a more intriguing concept, one which reflects its many contextual aspects, rather than a ‘house’ as a merely physical product. The first scene of the movie *“A House is Not a Home”* (Russell, 1964), opens with the following song:

A chair is still a chair
Even though there's no-one sitting there
But a chair is not a house
And a house is not a home
When there's no-one there to hold you tight
And no-one there you can kiss goodnight

In this song, there is the idea of home as something which acquires its meaning by a person who lives in the house, so the distinction of home from a house is not attributed to an affiliation with the objects or other physicalities of the house, but interpersonal relationships within the house. Therefore, even though a 'house' has a potential to *become* a 'home', it can be suggested that the fact that they are not conceived as synonyms, and that the latter implies the complexities regarding one's experiences should be taken into account while considering how the concept is represented. Not all uses of the term seem to imply appreciation of the complexities that we might find in some personal accounts as well as artistic work, and moreover, there seems to be an attempt to fix meanings on the term by certain bodies. In 1996, Brian Waters wrote an article titled, *When a house is not a home*, explaining that the UK government determines if a house is a home by assessing the activities within the dwelling; a*bnormal* activities, such as working or having a small business inside a house do not deem it a 'home'. This implies some *tangible* criteria on which 'home' is based. Governmental regulations based on such criteria show a tendency to attach certain meanings to the concept which have a potential to reduce the complexities of home to institutionalized definitions. Four decades before Marklee's book was published, there was an article written with the title, *"A House Is A House Is A House"*. However, the authors opened their writing stating that this was false, "*BUT IT ISN'T. Roses are different. So are houses."* (Burns, 1972, p. 407).

The appearance of the term 'home' on magazines dates back to the eighteenth century (Blunt & Dowling, 2006), and the ways in which home has been represented through these media have been considered as means of promoting certain conceptions of home. Pearson and Richards (1994) mention the rise of the use of the term 'home' in advertisements for housing estates in the twentieth century in Britain (p. 5). Today, it feels almost natural to see ‘homes’ on the front pages of brochures of construction companies and holiday catalogues.

The Scotframe (2016) housing manufacturer brochure cover is presented as follows: A vertical page with the name of the company on top with stenciled typography, subtitled with “timber frame | homes”. In the middle, a symbolic image tags as “Homes Portfolio”. The image is composed by a *springy* endless yellow flower landscape under a sunny blue sky, where an apparent family — a couple with a young girl — are seen from the back staring to the horizon; all of them wearing jeans and white shirts, holding hands. They could have a romantic resemble with a movie *finale,* walking forward and *living happily ever after;* but there is something imposed in front of them, a shiny spectrum, a ghost… a Home. The contour of a detached house *float* over the flower field. Finally, the cover page contains a bottom note, which says “designs for your lifestyle”. The term ‘home’ is presented in relation with intangible concepts, like: dreams, hope, eternity or all other probable interpretations from the image used. But, why the interest of the company in presenting these ideas in a consumerist medium? Is that abusive or manipulative, or are the companies really capable of producing homes rather than houses?

In the same brochure, the page after the cover reveals another intriguing image composition; similar country grass landscape and elements, but now the perspective has changed, you are looking at them. They are lying down on the grass, smiling. The couple now is accompanied by a dog, and the house contour is *framing* them. Below them is the following statement: *‘Your* life / *Your* home / *Your* way // Now is the time to build *your* own home' (Scotframe, 2016, p. 2). The way the word 'Your' is repeated is similar to how Stein *plays* with the language in the sense that, there is no final statement about the product, but rather the possibility of interpretations around the idea of the customer who is in control over the design of the product — the house. If it is the potential occupants who would turn these houses into homes, we are left with questions about when the activity of homemaking begins, what it consists of, and what exactly the role of the industrial companies in relation to this process is.

Conclusion

In 2010, with the objective to establish relationships between industry and academia in order to develop *sustainable built environments for people with different socio-economic backgrounds,* the ZEMCH —*Zero Energy Mass Custom Home*— Network was founded (ZEMCH 2017). Dr Masa Noguchi, the founder coordinator of the organization, emphasized the 'selection' of the term 'home' over 'housing' reasoning that 'housing' —driven from house— is seen as a construction process, but 'home' refers to the way people live. On a personal interview (Jimenez-Moreno, 2016), Dr Noguchi stated the following:

> ...in Japan, they don't say 'home', they call it in Japanese language. … I feel really comfortable using Home rather than Housing, or Living Unit, which is more like a product, commercialised product. … Home is just natural, it is where family gets together, people come back, children grow; for me it is like a 'nest'. Home sounds 'softer and warmer'; housing and dwelling are more mechanised. That's why ZEMCH uses homes instead of housing. … House is another thing. 'House is also very close to the product. There is a common idea of 'turning a house into a home', I agree with this common sense...

Dr Noguchi, remarks his *comfort in* using 'Home' because he thinks that it is beyond what 'house' suggests. In his accounts where he categorises industrial and marketable concepts against the values of home, home is suggested as the *optimal* goal capable of bonding a dwelling emotionally with his inhabitants, which should be addressed despite the domination of the construction process that is at play. The major problems regarding these ambiguities around the representation of home by industrial companies is obvious when *living somewhere* ceases to be a conventional activity, such as the conditions of displacement and several forms of homelessness, where it is especially important to question agencies and processes regarding one's relationship with place. One example where these problems come to surface is the production of housing units that are developed for the refugee camps. In the back cover of their book *Construction and Design Manual: Container and Modular Buildings* published in 2016, Dörries and Zahradnik raise concerns about housing for the displaced people by stating their question as following: "[However,] are tent cities and containers the only solution in creating cheap accommodation and a *dignified home* as quickly as possible for displaced persons?" and they offer a range of modular buildings with varied technical qualities that might be of use for the so-called refugee crisis. What we suggest is that searching for a *dignified home* in a catalogue is disregarding the core problems. If one considers home to be something that can be produced industrially, it seems inevitable to look for the ways to determine the industrial properties that could make it most 'homely'. Such a take on the issue can also be found in an explanation about a housing unit developed by the collaboration of Better Shelter, IKEA and UNHCR where "safety, security and dignity" are claimed to be maintained by technical processes:

> …The Better Shelter becomes their home away from home in temporary settlements, transitory sites and camps—a place where they can close the door and get a little privacy and calm. The shelter resembles a house, with semi-hard, non-transparent walls. It has four windows and a high ceiling, enabling residents to stand upright inside. The door, lockable both from the inside and the outside, lets everyone—and women and children especially—feel safer when they are at home. A solar powered lamp provides light during the hours of darkness. The shelter allows residents a higher level of safety, security and dignity than a tent (*Better Shelter: Safe and dignified*, n.d.)

Home seems to be difficult to get to for an outsider -if there is such thing as an outsider. We have argued in this study that, in terms of its affiliation with 'house', 'home' is already a concept which is charged with the complexities of people's experiences, which facilitates examination of how this relationship is conceived by several actors through its representations. The claims of industrial companies as to deliver 'homes' have a potential to yield the reduction of the complexities embedded in 'home', and the idea that the industry is capable of providing people with 'better homes'. However, the necessity of questioning such possibility for the industrial companies to design or construct homes rather than just houses persists.

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Academic Paper

Barriers to Innovative Housing in Scotland: NRGStyle's 'ZEMCH 109' Case Study

The work presented in here was previously published in ‘ZEMCH International Conference proceedings 2018, Melbourne’, named as ‘Barriers to Innovative Housing in Scotland: NRGStyle's 'ZEMCH 109' Case Study’ by Pablo Jimenez-Moreno, Pablo, Alison Quinn, Norrie Smith and Chintan Kantute. This study was conceived by all of the authors. I, Pablo Jimenez-Moreno and the Author of the thesis, carried out the writing of the paper and collection of material.

Barriers to innovative housing in Scotland:
NRGStyle's 'ZEMCH 109' case study

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Abstract: This paper presents a detailed description of the 'ZEMCH 109' project— a case study for the delivery of 'Zero Energy Mass Custom Homes (ZEMCH)' in the UK by NRGStyle, a Scottish entrepreneurial organisation. The paper aims to identify the processes, possibilities, barriers and limitations that industries may confront when applying ZEMCH theories in practice. Moreover, this paper describes the particulars of this project and recapitulates the academic studies referenced/developed around it. NRGStyle intend to attach new sustainable houses to existing post-war houses with generous plots. As a result, the owners could move to a super insulated house capable of generating clean energy, while the existing dwellings could be retrofitted and used for rental purposes. Mass customisation manufacturing processes are intended not only to ensure energy and resource efficiency through off-site construction, but also to achieve design flexibility that follows the principles of 'multi-generational homes' and to accommodate users' wants and needs. ZEMCH 109 began with the ambition to eradicate fuel poverty in Scotland by means of constructing "eco-houses". In 2009, the Mackintosh School of Architecture collaborated by collecting data from an existing property in Prestwick, Scotland, to generate the initial designs. A feasibility study was then funded by "CIC Start", Glasgow Caledonian University, whereby cost-effectiveness, energy efficiency and waste reduction aspects of the designs were analysed. After which, the Building Environments Analysis Unit (BEAU) of Sheffield University monitored the energy usage of the selected case study. Presently, NRGStyle is applying for the construction licence to erect a prototype show house. Ongoing research with the University of Edinburgh is focusing on how mass custom manufacture and marketing processes are linked to the delivery of zero energy houses. Finally, this paper also covers ongoing research into resource efficient materials and Circular Economic business models.

Keywords: Planning Applications, Housing, ZEMCH, NRGStyle, Theory application.

Introduction

When Norrie Smith developed the idea of constructing eco-houses in 2005 and later incorporating the NRGStyle company in 2011* to host the project, he could not have imagined the long and complicated journey he was about to embark upon (Companies

House, Department for Business, Energy and Industrial Strategy). This was mainly due to the fact that the ambitions of his project not only relied on dwelling, but in the search of achieving social *justices* through the construction of houses. Houses that aid in abolishing fuel poverty, reuniting families and promoting mental, physical, and social health. Back then, an ‘Eco House’ was the closest term he could find to encompass his idea.

The development of the project has involved continuous research and development, as well as multiple learning processes. The decision to incorporate academia resulted in the adoption of the ZEMCH term— Zero Energy Mass Custom Home— where the project found a frame correlating with its ambitions. The project prototype will be constructed in Prestwick, Scotland, at 109 Adamton Road South. Therefore, the project has been named ‘ZEMCH 109’.

This document provides insights and explanations into the bureaucratic processes crucial for building in Scotland. It narrates the ‘ZEMCH 109’ journey from NRGStyle’s perspective, from its conception to current state. This study was developed following a rigorous examination of the NRGStyle’s archive. The author’s aim was to identify the moments where the project confront barriers for its completion, looking for the gaps where scientific (academic) conjectures conflict with the practice.

Definition of the project

The ‘ZEMCH 109’ project aims to construct ‘net zero site energy houses’, which means that the houses constructed will produce at least as much energy through renewables as they consume, when accounted on the grid interaction at the boundary of the building site (Sartori et al, 2012: 10; Voos and Musall, 2013: 12; Torcellini et al., 2006: 4-5, 11; Aelenei et al., 2015: 277, 293; Marszal et al., 2011: 972).

The Prestwick prototype will work as a show-house and example for its replication in similar plots around the UK. The proposed houses will be attached to existing end-of-terrace houses with generous plots; as a result, the owners will be able to move into a new super-insulated house equipped with energy-efficient mechanical systems, while the existing dwellings are able to be retrofitted and used for rental purposes (NRGStyle).

The intended houses can be produced following a standardised construction system, but the outcome (house) has to adapt to each specific context– plot size, latitude, orientation and customer financial capacity– therefore, mass customisation strategies will be utilised to mediate these factors without modifying its procurement system. NRGStyle is the agency that will manage the marketing, production and delivery of the zero energy houses.

The Journey

In 2005, Norrie Smith started running a ‘Neighbourhood Watch’ scheme as a response to the unsafe social conditions (Scottish Crime Prevention Council). The scheme successfully brought the community together and consequently evolved into a ‘Regeneration Project’ that worked to improve the local built-environment. The ‘Raploch Regeneration Project’ and the ‘Home zone’[25] principle were used as conceptual references to start shaping the project (Robertson; Kaiya, 2016).

[25] A ‘home zone’ is defined as the residential street where people come before vehicles (CIHT-4).

It was observed that the construction of the built environments, in particular those financed by individuals, require high investments that people in poor areas are not capable of funding. It was also noted that a significant percentage of their income was utilised to pay for energy bills, to the extent that increasing cases of 'fuel poverty'[26] were becoming evident (fig. 1). Therefore, the generation of energy through renewables was considered as a logical solution.


Half of families miss out on huge savings on their gas, electricity and telephones
MILLIONS PAY £270 TOO MUCH ON BILLS

PRIEST QUITS HIGHLAND PARISH TO CARE FOR LOVE CHILD
SCOTTISH DAILY EXPRESS 35p
Our brilliant astrologer Lori Reid reveals how your life is going to change NOW
Scots pupils bribed with iPads to eat their greens
£434 EXTRA ON ENERGY BILLS
Families forced to pay for new

Electric bill shock for eco-home residents
By Edwin Lawrence

Figure 1: Media (newspaper) coverage of the 'fuel poverty' situation in the area [NRGStyle archive].

The approach to energy efficiency has been the most significant learning curve for the project and the central driver thus far. Research at that time consisted of attending energy fairs and training as wind turbine technicians. It was quickly understood that renewables do not represent a significant economic and environmental value if they are not merged with passive design strategies– airtightness and thermality. The initial idea was to retrofit existing dwellings, but retrofitting was considered a complicated process with uncertain impact. On the other hand, the construction of new 'eco-houses' is measurable and straightforward.

Through intuitive surveys in the area, a large number of end-of-terrace houses with room for the construction of new houses were identified. Given that it followed the desired characteristics, the house located on 109 Adamton Road South was bought in January 2007 with the construction of a prototype in mind. Several months later, an 'Outline Planning Application' was submitted for its construction, however the construction license application was refused some months after.

Actions towards social regeneration and sustainability are usually encouraged by politicians and governments; however, the 'ZEMCH 109' project has encountered obstacles in policies that have delayed its completion. The paper proceeds by presenting the execution of the project, planning application processes, its refusal and actions taken by NRGStyle in order to counteract them.

The Planning Applications

Outline Planning Application

The first planning application process lasted from March 2007 to June 2008. An 'Outline Planning Permission for the erection of dwellinghouse'[27] was submitted through a local Architect[28] (NRGStyle (a), 2007). Statutory basic information was

[26] A fuel-poor household is defined as one which spend more than 10% of its income on energy to heat its house to an adequate standard of warmth (Energy UK).
[27] At 109 Adamton Road South, Prestwick, with the following reference number: 07/00380/OUT.
[28] David Campbell from 'Architecture Design and Development Solutions'.

supplied including location and block plan. No architectural plans, design statement nor reference to Eco House guidelines were required at this stage.

In May 2007, a letter from a council planning officer[29] notified that the policies H6 & H7 of the Local Development Plan (LDP)[30] were *'material to the consideration of [the] application'* (NRGStyle (b), 2007). A material consideration, in Scotland, is a process in planning law which the decision must consider during the assessment of an application for development when deciding the application's outcome. Policies H6 and H7, which were later 'Refusal Reasons' stated in 2007, are the following:

*H6— 'the layout, density, plot ratio, scale, form and materials of any proposed development not detracting from the character of the surrounding buildings and the locality; and… The **provision of an acceptable residential environment**/ amenity being provided'*

*H7— 'Within areas predominantly in residential use as identified on the Proposals Map, **the Council will seek to protect the character and amenity of the area** concerned, especially from non-residential development with potentially adverse effects on local amenity.'* (emphasis added)

It was advised to revise these policies on the council's website. However, they were not available online at the time of writing; they have most likely been superseded by the most recent LDP.

It was also stated that *"… the proposed development would interrupt the rhythm of the street…, unduly compromise the established character of the area and… would have an adverse impact on the visual and residential amenity of both the existing and proposed properties."* Finally, it was suggested to submit a **written** statement to attempt to justify the proposal (NRGStyle (c), 2007).

Therefore, in June 2007, a response supporting the application was submitted arguing that (from NRGStyle's perspective) the application submitted complies with the mentioned policies; backing up the argument by referring to existing extensions approved in the area, including the one located on the site.

It was also expressed that the arguments and policies were subjective and lacked measurability, e.g. it was doubtful to state the proposal would *interrupt the rhythm* of the street compromising the *character* of the area, when it is composed by an eclectic combination of housing types (detached, semi-detached, terraced and flats) and styles dating from different eras (NRGStyle (d), 2007).

At this point, construction details or design representations couldn't be submitted; therefore, it was compromised that the quality and design styles would conform to the mentioned policies.
Outline Planning Application Refusal

[29] South Ayrshire Council Planning Officer, David Clark.

[30] The South Ayrshire Local Plan (SALP) is the land use plan that sets out strategic spatial priorities and policies for specified uses (South Ayrshire Council).

The Outline application was refused in August 2007 stating that it was contrary to the above mentioned policies H6 and H7.

The hired architect advised to appeal at National Government level, as there was no objective reasons for the refusal. Therefore, in September 2007, an appeal was submitted to Scottish Ministers at the Scottish Government Inquiry Reporters Unit in Falkirk. The appeal contained all the information submitted in the Outline Planning Application and a supporting letter from the neighbours.

Outline Planning Application Refusal Appeal

As part of the appeal procedures, a Scottish Government Reporter[31], accompanied by the council planning officer in charge, visited the site in April 2008. The applicants were permitted to attend but not to speak to nor approach the Reporter.

The appeal decision was **dismissed** in May 2008, which meant that planning permission was refused under the appeal process. The reasons stated for the dismissal followed the Planning Application Refusal, arguing again that the proposal runs contrary to the already mentioned policies H6 and H7. The objecting points remained subjective declaring that *"…the development …would be unsympathetic in relation to the planned form of the area [sacrificing] the symmetry of the terrace, and appear[ing] out of place…"* Moreover, the mentioned similar existing examples were not considered comparable to the proposed site. The community supportive letter was noted, however, the council's concern was that by allowing the proposal, this would set a negative precedent.

The Reporter's decision was *final*[32]. Consequently, a new planning application could not be submitted for another two years from the date of the Reporter's decision.

A senior planning manager and an elected councillor visited the site and commented,

"if it [the application] had landed on a different planner's desk on a different day, then planning permission would have been granted".

This statement, not only reinforces that the planning process loses subjectivity when justified with unmeasurable policies, it also suggests a matter of *luck,* which refers to the criteria, capability and efficiency of the planning officer determined.

In June 2008, a supportive Councillor[33] attended a meeting with the Head of Planning and a Senior Planner to discuss the proposal and its outcome. It was informed then that planning history would be taken into account in further procedures even in applications resubmitted after the two year's time gap. Advised by diverse councillors it was decided not to appeal and invest (the time and money) on preparing a new planning application.

Planning Application Interim Period

[31] Ms Allison Coard.

[32] Could only be reconsidered if any person was *aggravated* in the process, conferred in Sections 237 and 239 of the Town and Country Planning (Scotland) Act 1997.

33 Hugh Hunter

In January 2009, the original architect was discarded and an Independent Planning Consultant[34] was commissioned to prepare a report over the planning decision. It was not until this date, that the applicants were able to see the council notifications and previous consultant reports. The new consultant noted that 'green credentials', although laudable, would NOT overcome the Council and the Reporter's decisions. She finally suggested to meet the council's Planning Manager[35] before "…*getting more detailed plans drawn up to demonstrate what you would like to do."*

In February 2009, the applicants met the Planning Manager and Officer, the latter who refused the previous planning permission. The Planning Manager explained her officers' point of view and gave the applicants the same courtesy. The Planning Manager could not see any apparent issue and asked the Planning Officer if planning permission could be given to an alternative proposal on the same plot. He refused and was visibly uncomfortable at the suggestion, insisting that *'South Ayrshire Council could not be seen to be doing a U turn!'*. The manager herself drew some diagrams on paper and suggested the applicants elaborate with architectural drawings and arranging another meeting.

At the time of writing, the advises given by diverse consultants opposed to each other and, only two years after starting the first planning application process, it was finally advised to elaborate an architectural design. The council planner's ironic contradiction emphasised the subjectivity of their decisions; and demonstrate that 'planning applications' are linear bureaucratic processes, where planners resist to modifications as they might imply re-work.

On the coming months, efforts were focused on consolidating a political network that could *back-up* the project, getting the support of Mr Chic Brodie who went on to become the Scottish Government MSP[36] for the area and who continues to be a strong supporter of the project to this day; while searching for the adequate person to elaborate the design.

An academic was selected over an architect[37], in order to capture the ideas of sustainability and replicability. Dr Masa Noguchi, Lecturer in Architectural Technology and Code for Sustainable Homes Assessor, had a portfolio on 'Mass Customisation', which was considered more suitable for the project.

The Academia Approach

In February 2010, the collaboration with Dr Noguchi was initiated, who at that point was conveniently based on the Glasgow School of Art, working with the Mackintosh Environmental Architecture Research Unit (MEARU). Dr Noguchi suggested that one of his Masters Students38 become involved, who later visited the site and eventually produce a series of architectural designs.

The project was utilised as a case study for the design and test of architectural integration of Hybrid Solar Thermal Mass (HSTM) and heat waste management (NRGStyle and ZEMCH Network, 2012: 24). An environmental analysis of the site was developed, including sun and wind analysis, a thermal survey of the house

34 Greta Roberts– MA Dip TP Town Planning Consultant.
35 Catherine Parish– Lead Conservation Planner, Planning Service, South Ayrshire.
36 MSP stands for Member of the Scottish Parliament.
37 Architect Paul Barham from John Gilbert Architects, Glasgow.
38 Audrius Ringaila

envelope and equipment, and measurement of internal temperature, humidity and CO_2 (NRGStyle and ZEMCH Network, 2012: 26-31). Then, a design was developed in response to the negative aspects observed, which consisted of an adaptation of a model used in their previous studies. The proposal demonstrated an increase of heat efficiency obtained by maximising solar gains and with a smart use of the heat extracted from mechanical systems (boiler and kitchen extractor) and water used in utilities (washing machine, shower and sinks). The heat recovered, plus the obtained from PV/T panels, was proposed to be introduced through a mass concrete wall and parts of the flooring (NRGStyle, 2012: 35-36). This design, in conjunction with supportive studies, shaped the document submitted for the further planning application.

Application for Full Planning Permission
After careful deliberations and multiple meetings between NRGStyle, the planning consultant, academics and construction engineers from an industrial company[39]; a Full Planning Application was finally submitted in March, 2012. The application consisted of: location plan, ownership plan, block plan, architectural plans (floor, roof, sections and elevations), a design statement and an illustrative video (fig. 2 and 3).

Figure 2: (left) Perspective of ZEMCH 109 proposal, south view.
Figure 3: (right) ZEMCH 109 proposal with wind turbine, frontal view.

In addition, the application had an appendix, which consist of a series of academic documents that justify the dwelling's design, in terms of sustainability, which include: a 'Standard Assessment Procedure' (SAP) that demonstrate that the design was capable of achieving 'net' zero site energy capabilities. A PV/T assessment (fig. 4). Technical information of the construction system provided by the construction engineers. A socio-demographic survey of Prestwick, Scotland and the UK, which demonstrated that Prestwick had the lowest social housing stock in the region, where more than 20% of the dwellings in Scotland are terraced (NRGStyle, 2012: 90-96). An academic paper that presented how the knowledge obtained from technical visits to Japanese Housing factories was transferred to the prototype (Noguchi et al., 2011). And 9 different designs alternatives (fig. 5).

[39] Designers and Construction Engineers from Powerwall– Frame System Company based in Glasgow. Currently under an Administration status.

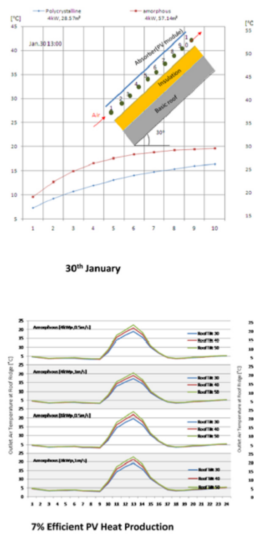

Figure 4: (left) Outcomes of analysis over the efficiency of PV in the proposed site.
Figure 5: (right) ZEMCH 109 alternative design proposals.

In short, it was a solid and well referenced document. However, it might be considered overwhelming, extent or out of normality. The council had troubles uploading and reproducing the video, which was a crucial part of the submission; and there were no comments on the academic papers or technical information, which suggests the authorities might overlook them or did not comprehend them.

In May 2012, the application for Full Planning Permission was refused. The reasons remain on the same line as the previous refusal. It was stated again *that the proposed dwelling house does not respect the scale, form and density of its surroundings and does not enhance the character or amenity of the locality.* The policies H6 and H7 were referenced once more.

On August of 2012, the first ZEMCH International Conference took place in Glasgow (fig. 6). NRGStyle had a pivotal position, not only on assisting in the organisation of the event, but with the 'ZEMCH 109' project taken as a case study of several of the papers presented. All the delegates were taken to visit the site, where Dr Avi Friedman highlighted the virtues of the project.

Simultaneously, an application was made to South Ayrshire Council to appeal the refusal decision (NRGStyle (b), 2012). An appeal at this stage is held by the Local Review Board (LRB), which is a Board of Elected members of the Council. A site visit was requested so that all members of the local review board could visit the site in person. The site visit did not take place.

The LRB meeting[40] was held in October 2012 and they upheld to the refusal (NRGStyle (c), 2012). As there were divided opinions, the decision went to vote, where councillors' arguments were stated in personal voice, e.g. *"I would not have a problem living next door to it"* or *"I wouldn't like to see that building when I'm out walking my dog"*. A councillor[41] who had previously assured interest in the project, left the proceedings before voting. The LRB decision was taken without the advice of any expertise on sustainability and was driven by personal judgements.

There was the possibility to select another plot in another Local Authority for the construction of the prototype; however, NRGStyle decided to insist over the same site to understand all the adversities that the project could confront in the future. Since then, the Planning Process has been on hold and the project was developed form other angles.

Parallel work

'ZEMCH 109' continued being used for academic studies. In 2012, monitoring systems were installed in the existing house to promote energy conscious behaviours (Han et al., 2012: 168). It demonstrated that the energy patterns have a correlation with the occupants' lifestyle (Han et al., 2012: 175). The same data was utilised by additional studies that assess the cost-effective relevance that passive design techniques and use of Photovoltaic Thermal (PV/T) systems and Mechanical Ventilation Heat Recovery (MHVR) (Rohatgi et al., 2012: 223; Dhamne et al., 2012: 613). These studies highlighted the significant effects of building orientation and thermal properties on reduction of energy demand. In 2013, Dr Noguchi extended the research of MVHR and PV/T systems. The study evaluated 19 different scenarios in order to identify their economic value over 10 years (Noguchi, 2013: 1256). Moreover, in 2013, the NRGStyle team attend to the 'ZEMCH International Conference' in Miami, USA, where another study developed around the project was presented (fig. 7) (Jimenez-Moreno and Noguchi, 2013: 85-100).

[40] A 'court room' style discussion where the applicants could only watch from the viewing gallery.

[41] Mr Hugh Hunter

Figure 6: (left) 'ZEMCH 2012 International Conference' reception and *official* photo: Dr Masa Noguchi, Chic Brodie, Norrie Smith, Alison Quinn and Paul Heron.
Figure 7: (right) NRGStyle team in the ZEMCH 2013 International conference in Miami, USA: (from left to right) John Onyango, Hasim Altan, Dr Masa Noguchi, Alison Quinn and Pablo Jimenez-Moreno.

In September 2013, NRGStyle members, accompanied by a selected group of experts in sustainability[42], were invited to a Scottish Government Meeting at Holyrood in Edinburgh to present their project and to discuss their experience, which helped that in 2014, the Scottish Government introduced Material Consideration in sustainable development (Scottish Government, 2014). Later that year, NRGStyle was referenced by the 'Home Renaissance Foundation' in a publication that promoted multi-generational Living (Housing LIN, 2015: 6-7). In 2015, Norrie was invited as a Speaker in the House of Lords at Westminster, London, to present the 'ZEMCH 109' multigenerational living qualities.

In 2015, Norrie introduced plans to build a housing factory in Scotland at the "ZEMCH International Conference" at the University of Salento in Italy. In 2016, part of the NRGStyle team attended the 'ZEMCH Mission to Japan' to visit the state-of-the-art facilities of leading housing manufacturers (ZEMCH Network). The knowledge gathered from the visit is being analysed for its successful application in the UK context. In parallel, complementary site works initiated in 2008 and completed in 2016, to adjust the site to some notes and advices observed in the application refusals. The prototype design has been modified during these years.

Future actions and targets

Foremost, NRGStyle will apply for construction permission for the ZEMCH 109 prototype. A new planning application will be placed in the coming months considering the same site, but a modified design proposal. It follows the outcomes obtained from the academic studies, but is shaped in a layout, form and style sympathetic to the surrounding urban context (fig. 8)

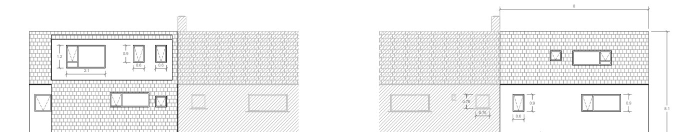

Figure 6: ZEMCH 109 design response to refusal (work in progress).

The new proposal considers the use of Scottish Cross Laminated Timber (CLT) for the structural shell. CLT envelopes have demonstrated to be highly airtight where insulation material can be easily attached. Moreover, its production process allows high customisation, in terms of where to *cut-out* openings. CLT boards can be outsourced until the company is capable of producing their own.

[42] Prof Tim Sharpe from MEARU, Gareth Feeney and David Fotheringham from the Scottish Government Sustainability Group.

The company will follow Circular Economy principles to ensure sustainability, not only on their operational life, but also during their construction and demolition. Circular economy refers to the economic model in which resources are reutilised instead of being disposed, maximising their value and regenerating products and materials at the end of each service life (Wrap).

ZEMCH 109 provides an excellent platform for introducing circularity in terms of resource recovery and multigenerational utility. Prefabrication and modular production allows the easy disassembly of the material so as to maximize recovery and regeneration at the end of its service life. Circular business models promote the selling of performance of certain goods than the good itself. However, the enterprise benefits, in terms of profit and reputation remain uncertain. Primarily because there is a direct competition with the traditional approach of ownership of tangible goods, in this case a 'house' (Planning, 2015).

Moreover, NRGStyle propose the retrofitting of houses as part of the project and is exploring the viability of adopting innovative circular business model regarding to: product recycling transformation and customisation possibilities in material recycled from construction.

Research will remain as the main drive for continuous improvement, which has been spotted as a key element of the project. Innovation and efficient application of new technologies is essential for the conception of zero energy dwellings. This study, not only demonstrates the barriers of implementing ZEMCH theories in practice, but will be utilised to promote the project in the academic and political circles. NRGStyle will develop an expert planning questionnaire to investigate whether these barriers to innovation are common place throughout. This questionnaire will be presented to all local planning authorities in the UK. The data will be collated and presented to ZEMCH 2019 for review.

Conclusions

The complexity of housing, as practice and concept, could not only be addressed only from a social stand point. The 'ZEMCH 109' journey demonstrated that planning permission can be refused even with the guidance of qualified consultants and academics. Despite being sceptical about the capability, efficiency and objectivity of the existing policies and governmental authorities; it has been understood that the success of a housing project relies on holding an adequate interdisciplinary team that work around architectural principles.

This paper presents the ZEMCH 109 project, describing its transformations to adapt to the limits and obstructions presented in its progress. ZEMCH 109— is a feasibility study for the development of zero energy houses through mass customisation systems— initiated as a 'scheme' to promote community security, which has evolved into a housing project. Its ambition consists of providing 'zero energy houses' to families that currently live in dwellings that do not accommodate their needs, in terms of energy efficiency, spatial flexibility and adaptability to family change.

The project was originated to overcome social necessities. Academics got involved to concretise the ideals into a prototype. Their approach resulted in the adoption of mass customisation strategies and zero energy theories and technology. However, even backed with scientific arguments, the prototype was not guaranteed with construction permission.

This study demonstrates that the application of innovative housing– energy efficiency– is highly dependent on modifying/adjusting to construction policies despite the high levels of scientific and academically engineering research made on during the design process.

Planning policies are focused on conserving homogeneous "traditional" urban appearances that conflict with innovative proposals. These policies do not reflect governmental ambitions towards carbon reduction and energy efficiency. Their modification process is slow and dependant to the efficiency and judgement of local authorities. NRGStyle have taken actions towards the modification of these policies. However, policies (new or old) are open to interpretation; therefore, the approval of new policies still do not ensure success on future planning applications. Moreover, planning applications are long and linear bureaucratic processes where previous refusals are carried, like stigmas, regardless whether or not there have been modifications in the law.

To guarantee planning permission, diverse entities were involved in the conception of the project: applicants (users), technical expertise (scientists), planning consultants, politicians and designers (architects). Ironically, it is unclear when the architectural or engineering expertise have to be included in a sustainable housing project. Housing planning applications can be initiated without architectural designs, fostering misinterpretations and premature verdicts over incomplete projects. The architectural practice, which is supposedly the expert entity in terms of sustainable housing, is not at the centre (or top) of the decision processes, empowering other entities that lack judgement on sustainable design, e.g. planners and consultants.

It has also been recognised that political support is crucial for a positive affect on the policy decision making process. NRGStyle has developed a significant effective and varied network, not with the intention of inducing politicians; but, due to the complexity of the project (sustainability), to certify a full understanding of it. It has been observed that decisions made by planners and local governmental committees could be taken precociously if they have to rush their decisions due to established bureaucratic timings and formats.

Acknowledgements
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